US009209802B1

(12) **United States Patent**
Maharyta et al.

(10) **Patent No.: US 9,209,802 B1**
(45) **Date of Patent: Dec. 8, 2015**

(54) **FREQUENCY SELECTION WITH TWO FREQUENCY SETS OF MULTIPLE OPERATING FREQUENCIES IN A MUTUAL CAPACITANCE SENSING DEVICES**

(71) Applicant: **Parade Technologies, Ltd.**, Santa Clara, CA (US)

(72) Inventors: **Andriy Maharyta**, Lviv (UA); **Ihor Musijchuk**, Lviv (UA)

(73) Assignee: **PARADE TECHNOLOGIES, LTD.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 197 days.

(21) Appl. No.: **13/629,281**

(22) Filed: **Sep. 27, 2012**

Related U.S. Application Data

(63) Continuation-in-part of application No. 13/429,869, filed on Mar. 26, 2012.

(60) Provisional application No. 61/602,750, filed on Feb. 24, 2012, provisional application No. 61/677,651, filed on Jul. 31, 2012.

(51) **Int. Cl.**
G01R 27/26 (2006.01)
H03K 17/955 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H03K 17/955*** (2013.01); *G06F 3/044* (2013.01); *G06F 3/0416* (2013.01); *G06F 3/0418* (2013.01); *H03K 2217/960705* (2013.01); *H03K 2217/960775* (2013.01)

(58) **Field of Classification Search**
CPC H03K 17/955; H03K 2217/960775; H03K 2217/960705; G06F 3/041; G06F 3/0412; G06F 3/0416; G06F 3/0418; G06F 3/044
USPC 324/681, 612, 613, 614; 345/173, 174; 370/254; 702/69
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,451,050 B2 11/2008 Hargreaves
7,643,011 B2 1/2010 O'Connor et al.
7,986,193 B2 7/2011 Krah
(Continued)

FOREIGN PATENT DOCUMENTS

EP 818751 A1 * 1/1998 ..... G06K 11/16
WO 2012108911 A1 8/2012

OTHER PUBLICATIONS

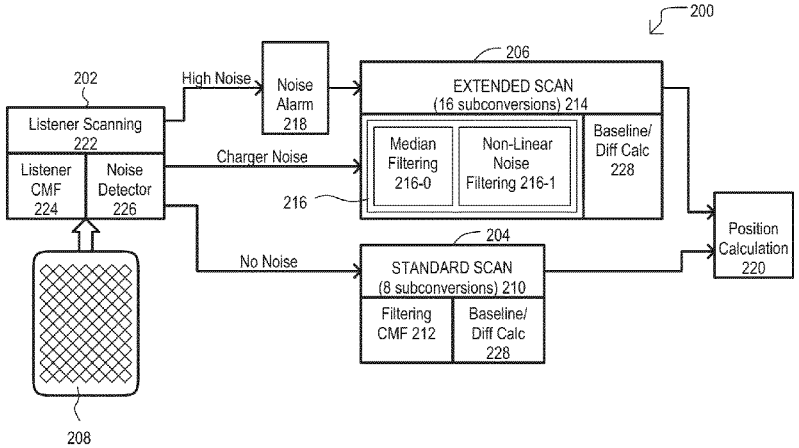
Carey, J. (Sep. 2011). "Noise Wars: Projected Capacitance Strikes Back," Cypress Semiconductor Corp White Paper, 8 pages.
(Continued)

Primary Examiner — Huy Q Phan
Assistant Examiner — David Frederiksen
(74) *Attorney, Agent, or Firm* — Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

Apparatuses and methods of frequency selection algorithms and frequency set selection are described. One method monitors a signal on the electrodes of a sense network, determine a first group of noise metrics of noise in the signal, determine a second group of noise metrics. The method switches from a first operating frequency in a first set to a second operating frequency in the first frequency set based on the first group of noise metrics and switches from the first operating frequency in the first set to a third operating frequency in a second frequency set based on the second group of noise metrics.

19 Claims, 27 Drawing Sheets



(51) **Int. Cl.**

G06F 3/041	(2006.01)
G06F 3/044	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0040079	A1*	2/2008	Hargreaves	702/191
2008/0157893	A1*	7/2008	Krah	331/177 R
2008/0158169	A1*	7/2008	O'Connor et al.	345/173
2008/0309625	A1*	12/2008	Krah et al.	345/173
2010/0085325	A1*	4/2010	King-Smith et al.	345/174
2010/0290633	A1*	11/2010	Chen et al.	381/57
2011/0037723	A1	2/2011	Huang et al.	
2011/0063993	A1*	3/2011	Wilson et al.	370/254
2011/0119320	A1	5/2011	Wu et al.	
2011/0134076	A1*	6/2011	Kida et al.	345/174
2011/0148810	A1*	6/2011	Kitada et al.	345/174
2011/0157077	A1*	6/2011	Martin et al.	345/174
2011/0175847	A1*	7/2011	Wang et al.	345/174
2011/0241651	A1*	10/2011	Oda	324/76.39
2011/0242045	A1	10/2011	Park et al.	
2011/0310051	A1	12/2011	Souchkov	
2012/0001859	A1	1/2012	Kim et al.	
2012/0157167	A1	6/2012	Krah et al.	
2012/0268415	A1*	10/2012	Konovalov et al.	345/174

OTHER PUBLICATIONS

Cypress Semiconductor Corporation. (2012). "Cypress TrueTouch Touchscreen Solutions," 7 pages.

Optoelectronics Electronics. (Aug. 24, 2012). "Avoiding EMI in Capacitive Touch Screens," located at www.optoelectronics-electronicspecifier.com/Displays/Avoiding-EMI-in-capacitive-touch-screens.asp, 4 pages,

Rosu-Hamzescu, M. (2010). "mlouch™ Conducted Noise Immunity Techniques for the CTMU," Microchip Technology Inc., 20 pages.

"Using TrueTouch Touch Screen can be Greatly AC Noise in Smooth Work," Shenzhen Easy Touch Technology Co, Ltd. 1 page.

ATMEL "Giving Touchscreen Technology that Personal Feel," 3 pages.

Search Report for "Frequency Selection With Two Frequency Sets of Multiple Operating Frequencies in a Mutual Capacitance Sensing Devices", Sep. 2012, 10 pages.

* cited by examiner

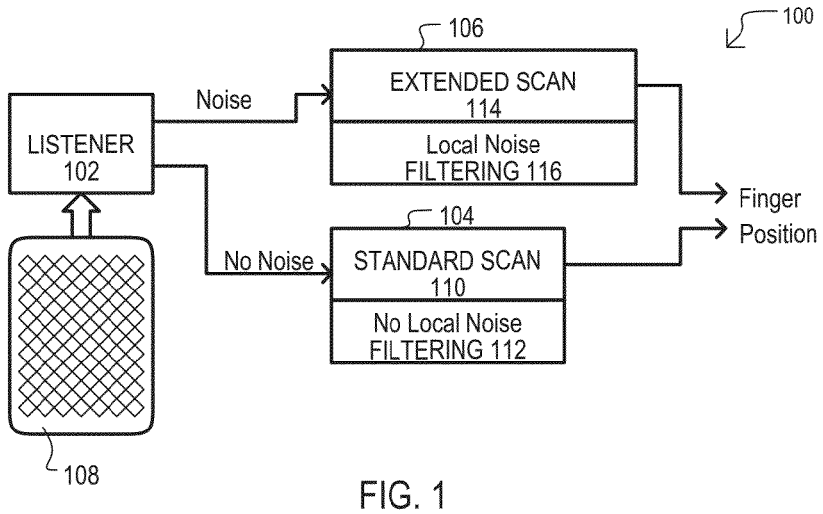

100
106
EXTENDED SCAN
114
Local Noise
FILTERING 116
Noise
LISTENER
102
Finger
Position
104
No Noise
STANDARD SCAN
110
No Local Noise
FILTERING 112
108

FIG. 1

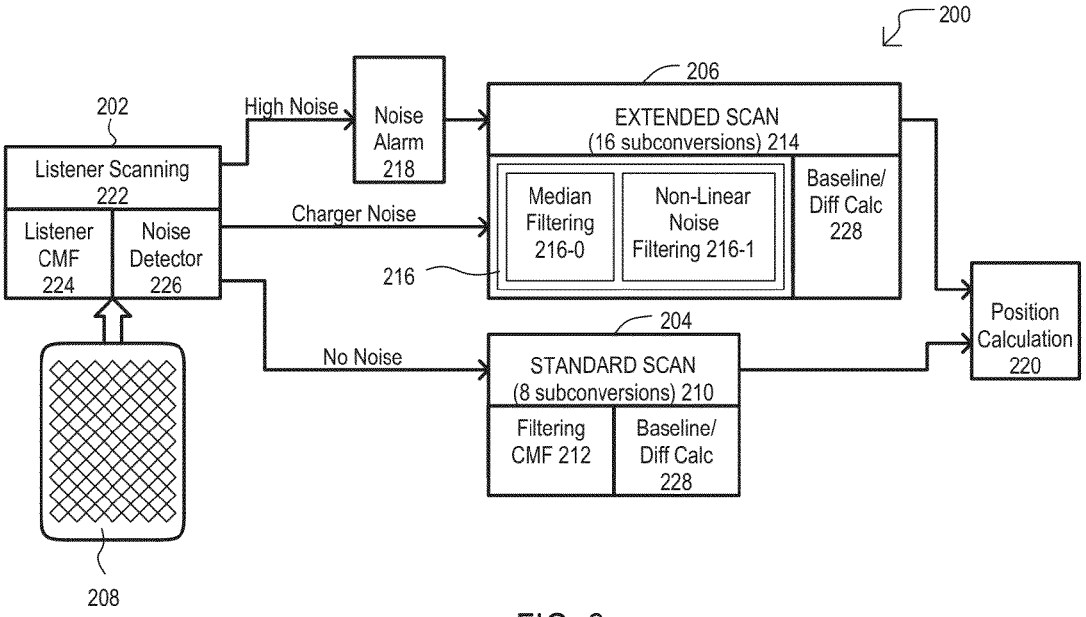

200
206
202
High Noise
Noise
Alarm
218
EXTENDED SCAN
(16 subconversions) 214
Listener Scanning
222
Median
Filtering
216-0
Non-Linear
Noise
Filtering 216-1
Baseline/
Diff Calc
228
Charger Noise
Listener
CMF
224
Noise
Detector
226
216
204
Position
Calculation
220
No Noise
STANDARD SCAN
(8 subconversions) 210
Filtering
CMF 212
Baseline/
Diff Calc
228
208

FIG. 2

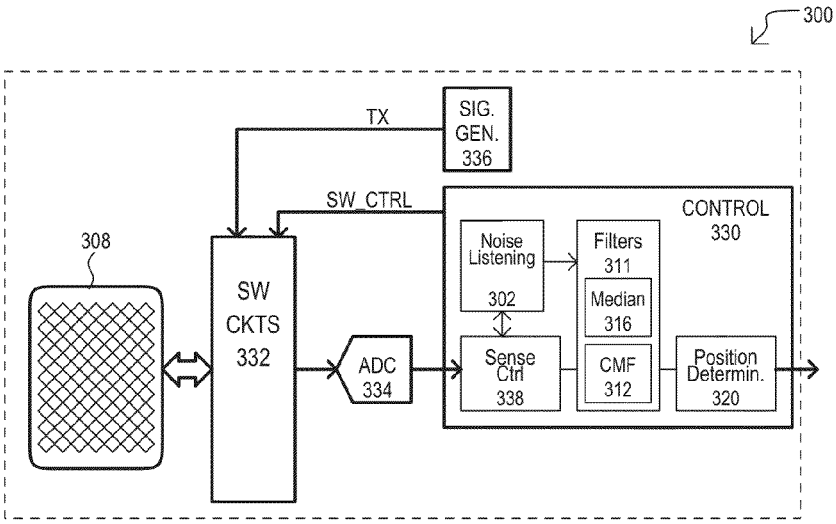

300
TX
SIG. GEN. 336
SW_CTRL
CONTROL 330
308
SW CKTS 332
Noise Listening 302
Filters 311
Median 316
ADC 334
Sense Ctrl 338
CMF 312
Position Determin. 320

FIG. 3

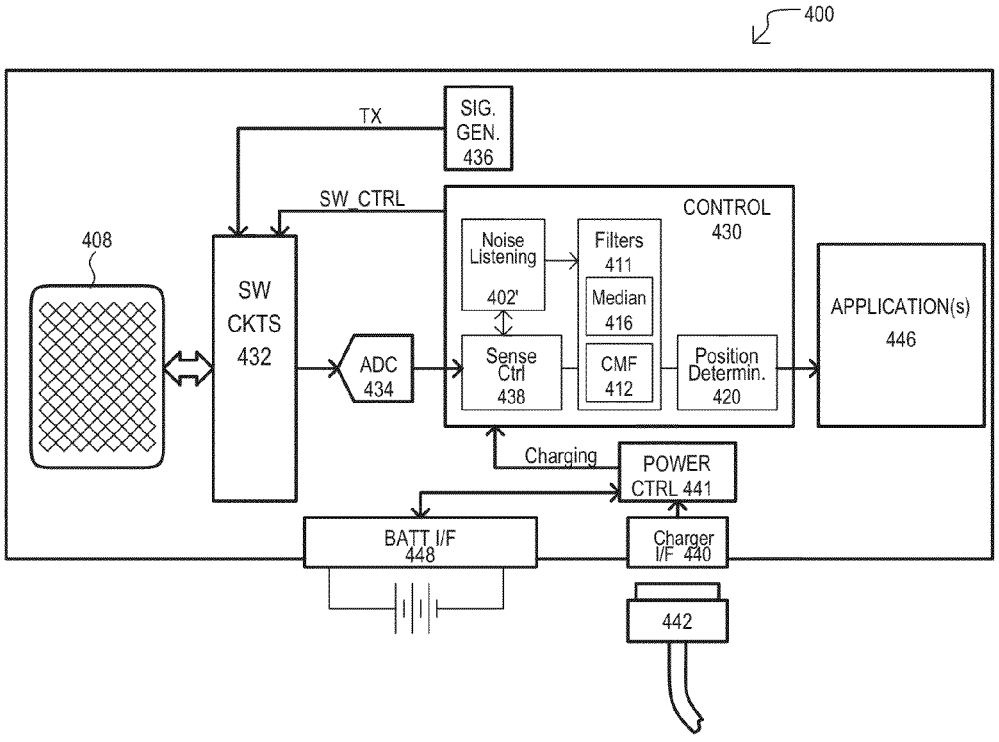

400
TX
SIG. GEN. 436
SW_CTRL
CONTROL 430
408
SW CKTS 432
Noise Listening 402'
Filters 411
Median 416
APPLICATION(s) 446
ADC 434
Sense Ctrl 438
CMF 412
Position Determin. 420
Charging
POWER CTRL 441
BATT I/F 448
Charger I/F 440
442

FIG. 4

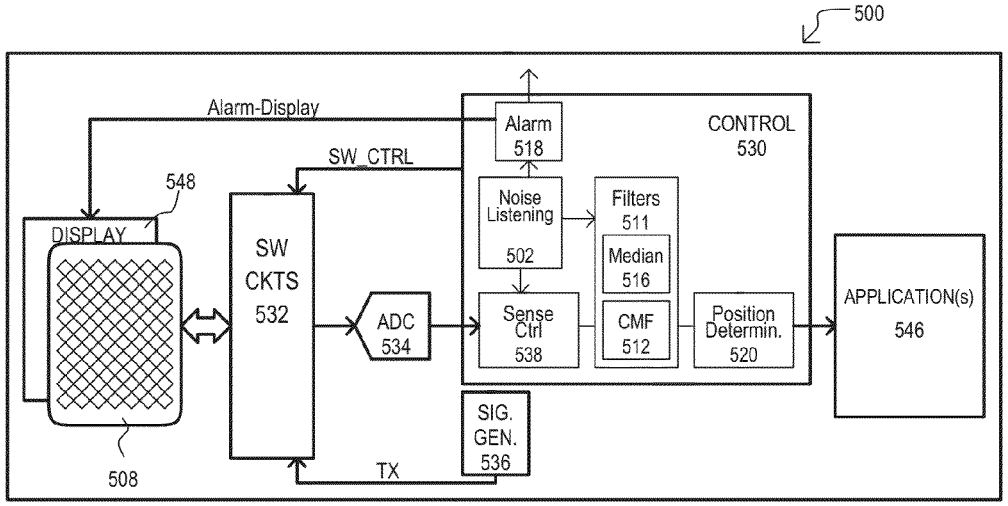

500
Alarm-Display
SW_CTRL
548
DISPLAY
SW CKTS 532
ADC 534
Alarm 518
CONTROL 530
Noise Listening 502
Filters 511
Median 516
Sense Ctrl 538
CMF 512
Position Determin. 520
APPLICATION(s) 546
SIG. GEN. 536
TX
508

FIG. 5

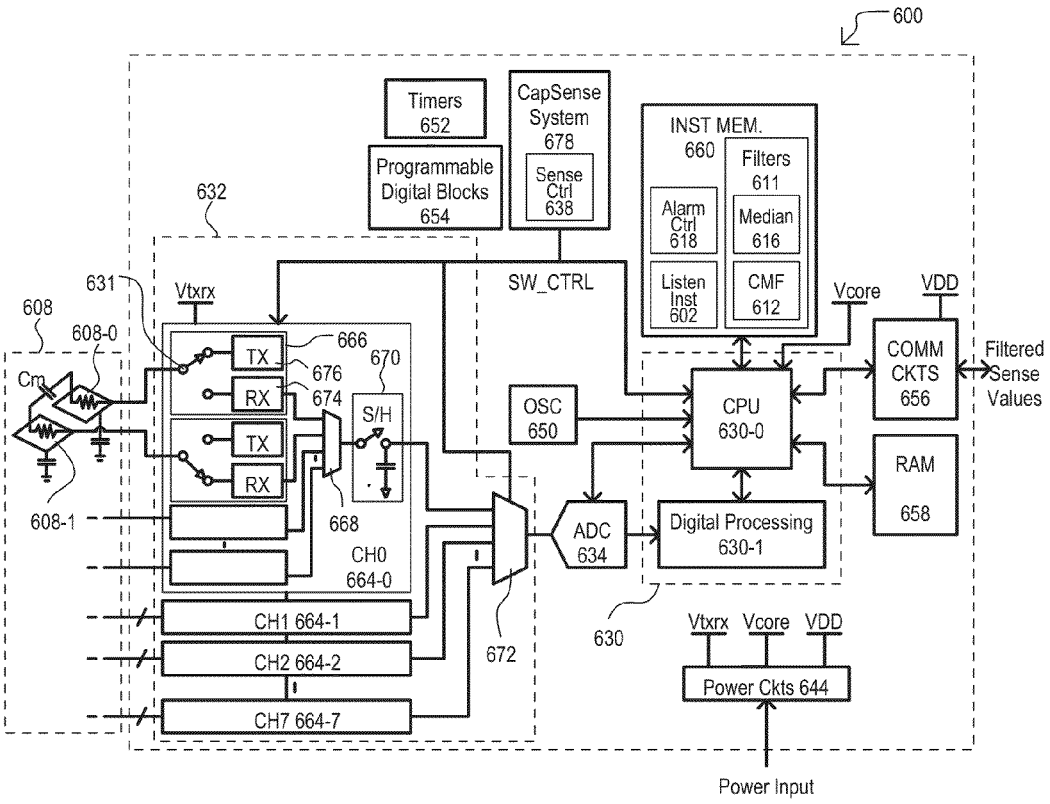

600
Timers 652
CapSense System 678
Programmable Digital Blocks 654
Sense Ctrl 638
INST MEM. 660
Filters 611
Alarm Ctrl 618
Median 616
Listen Inst 602
CMF 612
632
631
608
608-0
Vtxrx
SW_CTRL
Vcore
VDD
TX
RX
666
676
674
670
S/H
668
CH0 664-0
CH1 664-1
CH2 664-2
CH7 664-7
672
OSC 650
CPU 630-0
COMM CKTS 656
Filtered Sense Values
RAM 658
ADC 634
Digital Processing 630-1
630
Power Ckts 644
Power Input
608-1

FIG. 6

FIG. 7

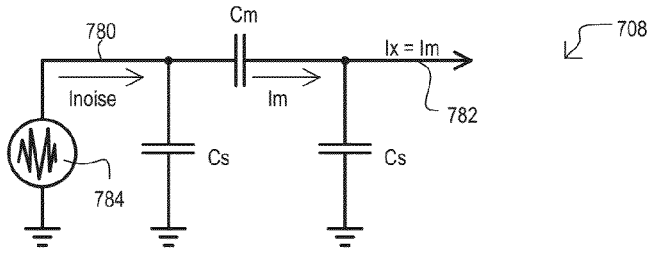


FIG. 8A

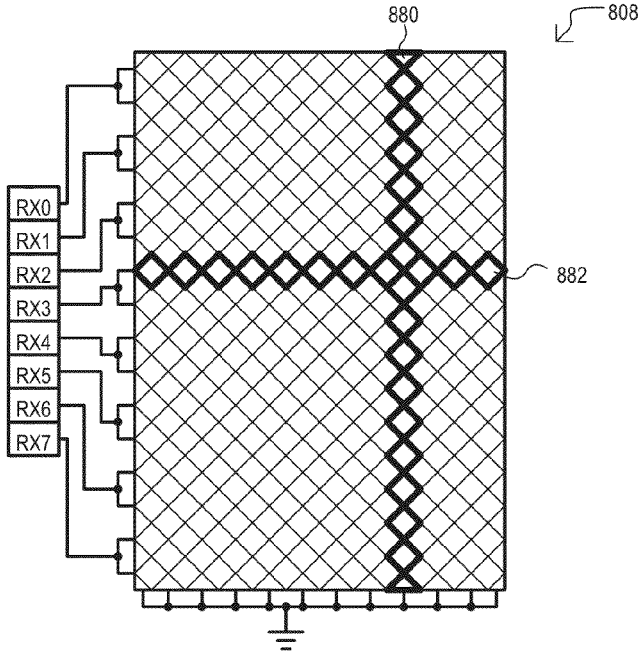
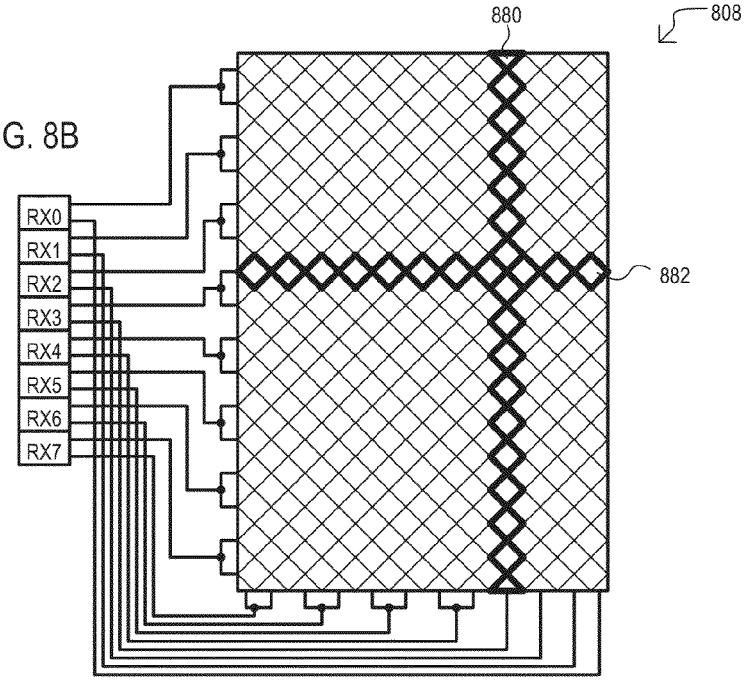


FIG. 8B



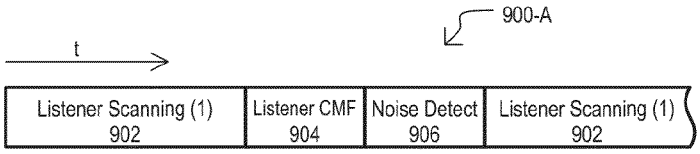


FIG. 9A

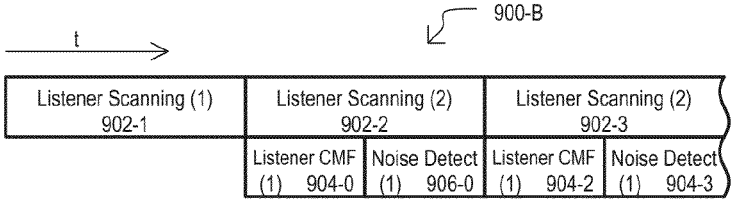


FIG. 9B

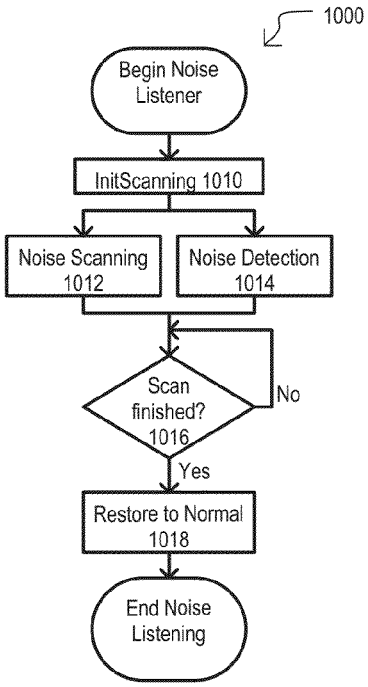


FIG. 10

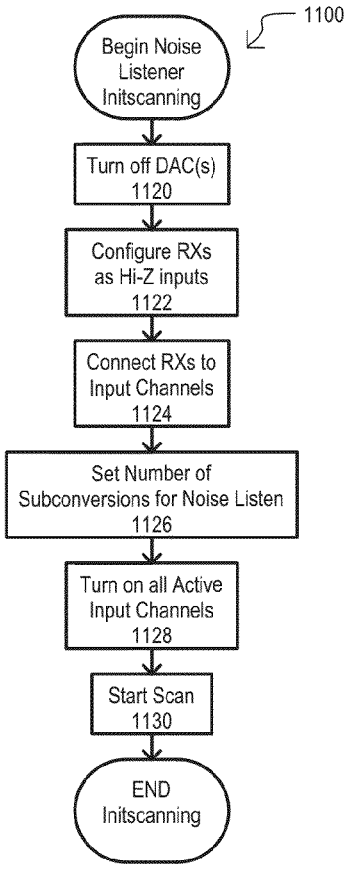


FIG. 11

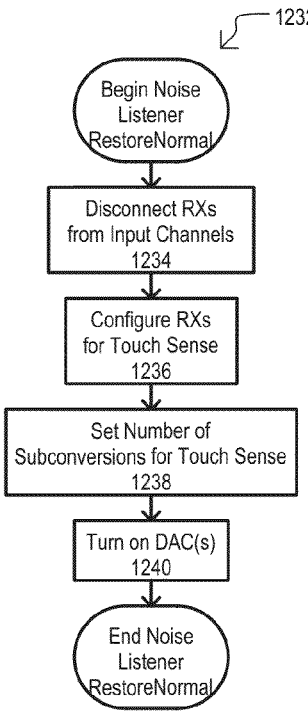


FIG. 12

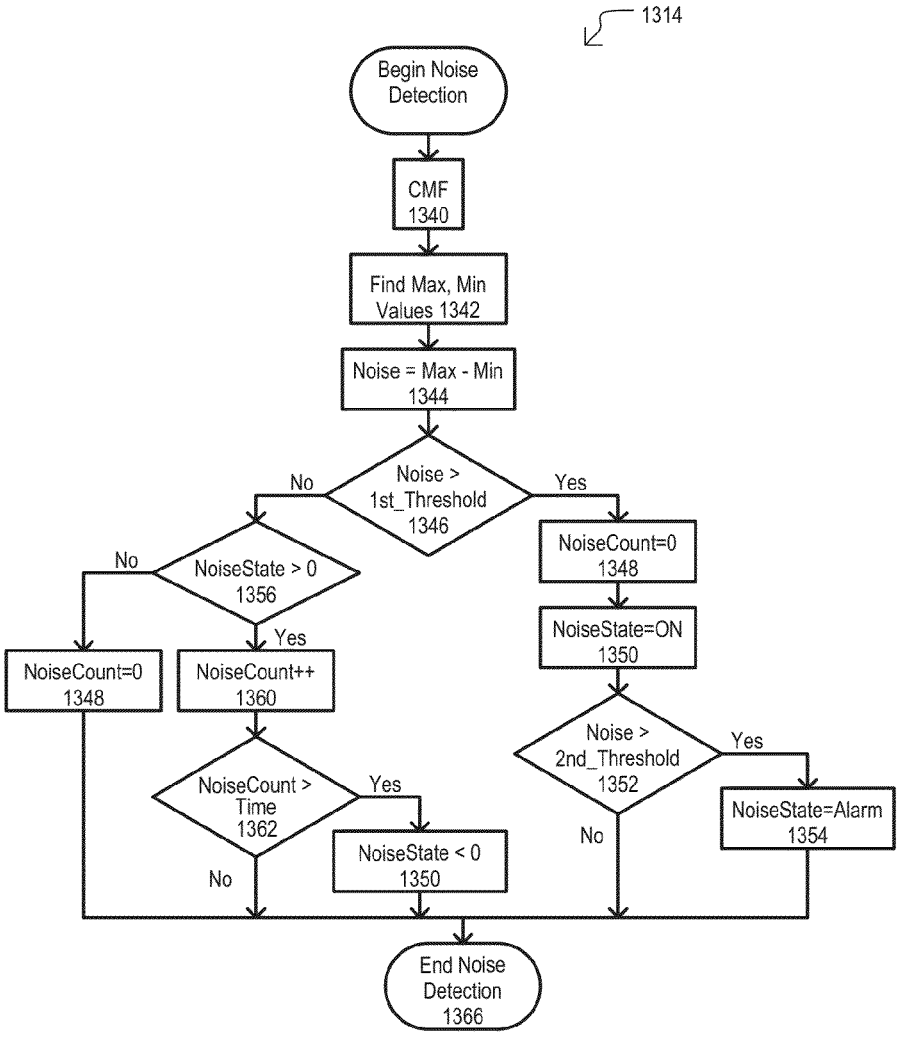

1314
Begin Noise Detection
CMF 1340
Find Max, Min Values 1342
Noise = Max - Min 1344
Noise > 1st_Threshold 1346
No
Yes
NoiseState > 0 1356
No
Yes
NoiseCount=0 1348
NoiseCount++ 1360
NoiseCount > Time 1362
Yes
No
NoiseState < 0 1350
NoiseCount=0 1348
NoiseState=ON 1350
Noise > 2nd_Threshold 1352
Yes
No
NoiseState=Alarm 1354
End Noise Detection 1366

FIG. 13

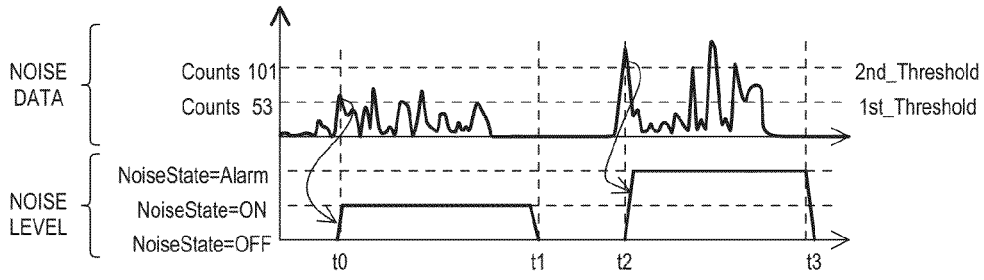

NOISE DATA
Counts 101
Counts 53
2nd_Threshold
1st_Threshold
NOISE LEVEL
NoiseState=Alarm
NoiseState=ON
NoiseState=OFF
t0
t1
t2
t3

FIG. 14

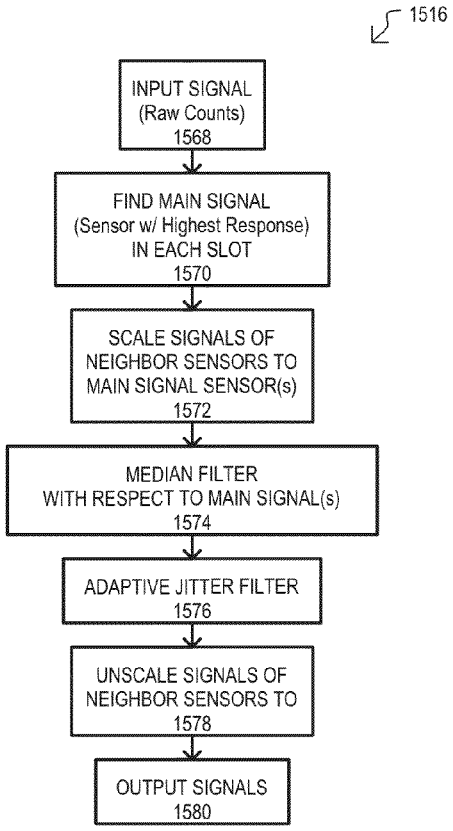


FIG. 15

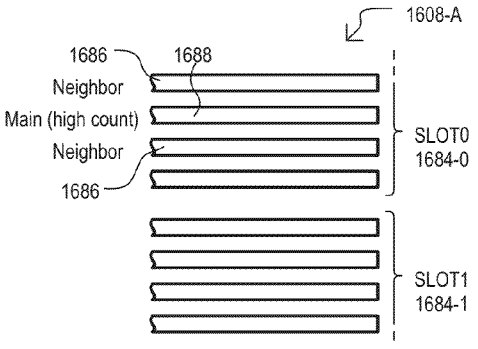


FIG. 16A

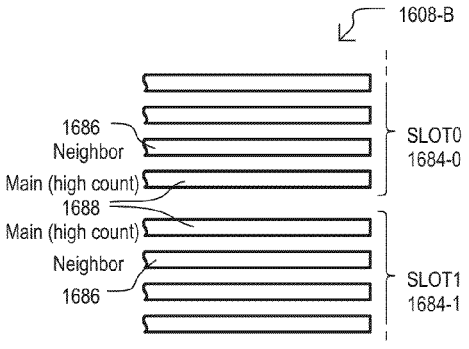


FIG. 16B

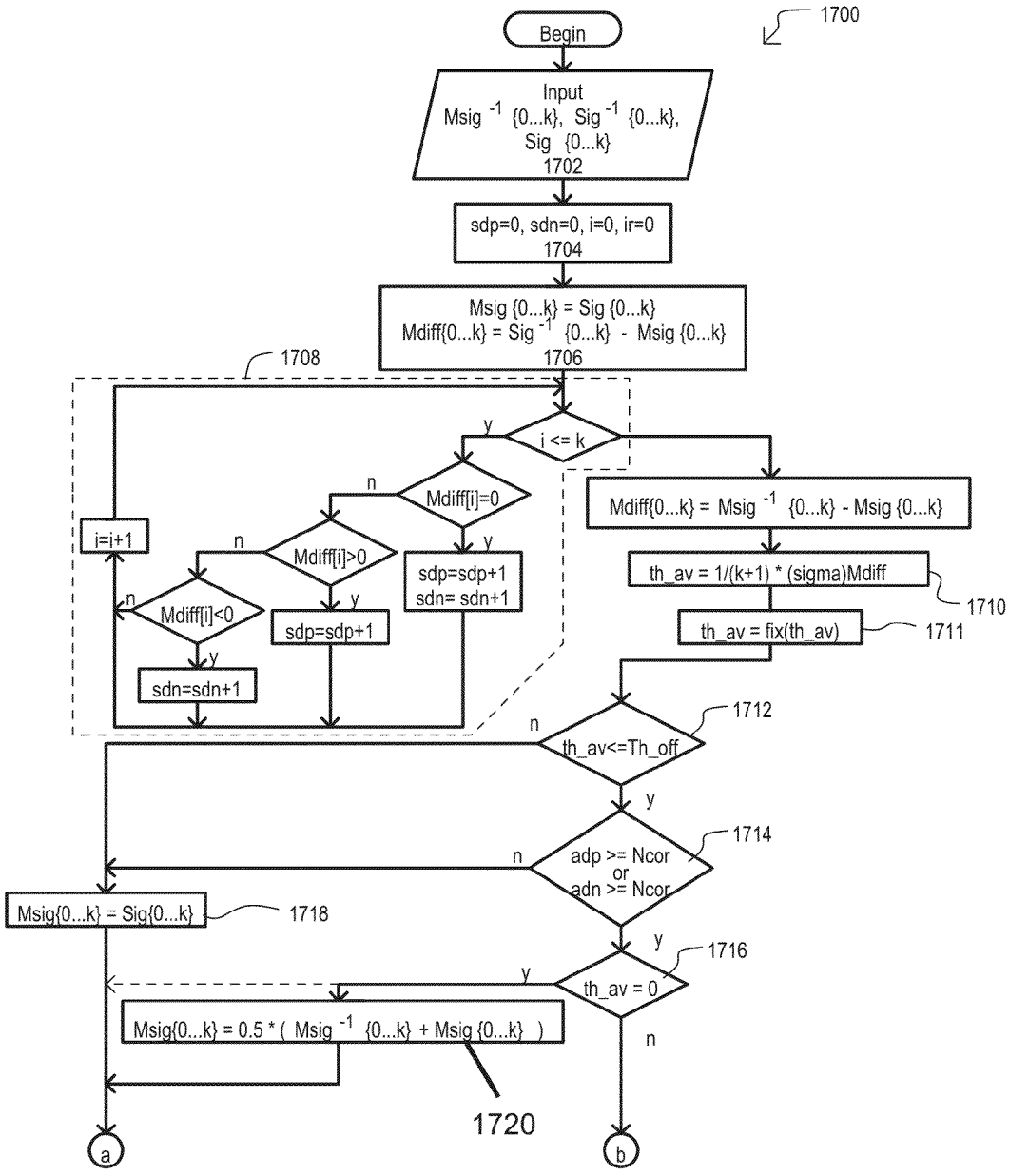

1700
Begin
Input
Msig -1 {0...k}, Sig -1 {0...k},
Sig {0...k}
1702
sdp=0, sdn=0, i=0, ir=0
1704
Msig {0...k} = Sig {0...k}
Mdiff{0...k} = Sig -1 {0...k} - Msig {0...k}
1706
1708
i <= k
y
n
Mdiff[i]=0
Mdiff{0...k} = Msig -1 {0...k} - Msig {0...k}
i=i+1
Mdiff[i]>0
sdp=sdp+1
sdn= sdn+1
th_av = 1/(k+1) * (sigma)Mdiff
1710
Mdiff[i]<0
sdp=sdp+1
th_av = fix(th_av)
1711
sdn=sdn+1
1712
th_av<=Th_off
1714
adp >= Ncor
or
adn >= Ncor
Msig{0...k} = Sig{0...k}
1718
1716
th_av = 0
Msig{0...k} = 0.5 * (Msig -1 {0...k} + Msig {0...k})
1720
a
b

FIG. 17A

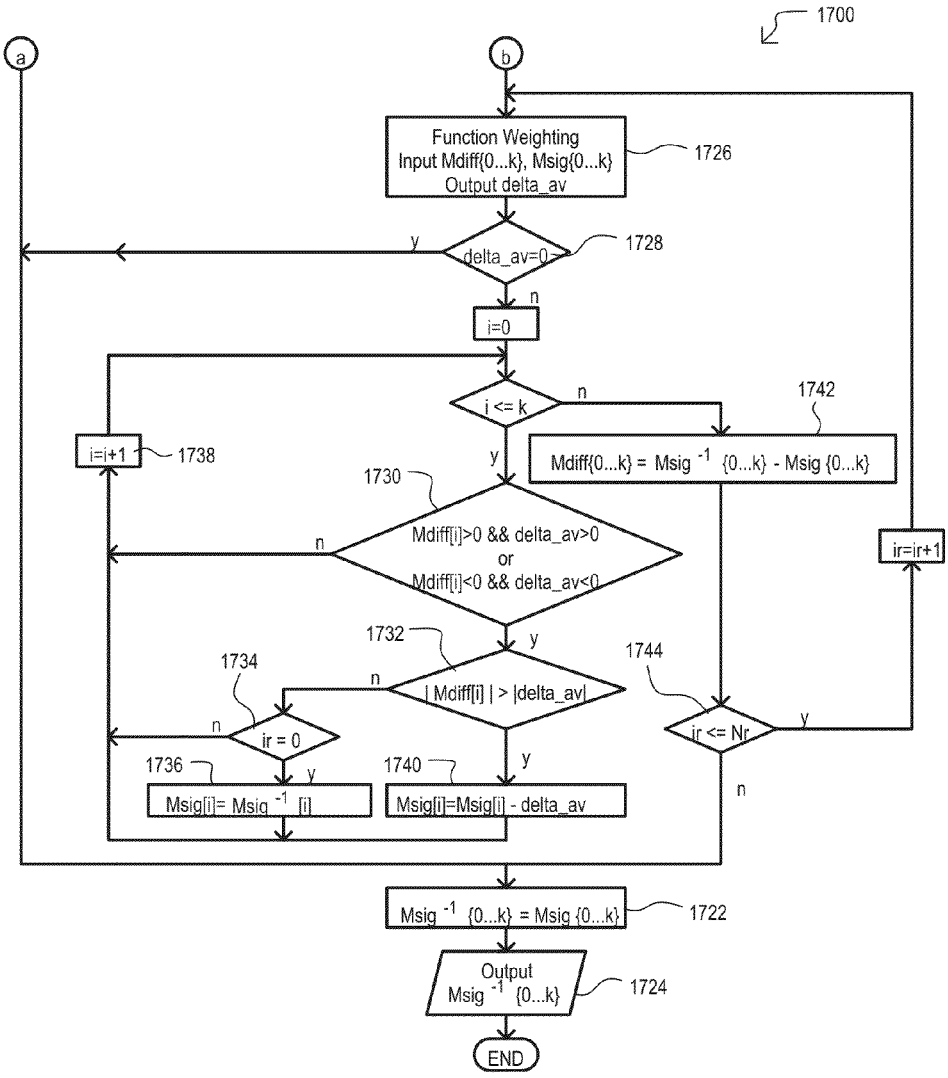

1700
a
b
Function Weighting
Input Mdiff{0...k}, Msig{0...k}
Output delta_av
1726
delta_av=0
1728
y
n
i=0
i <= k
n
1742
Mdiff{0...k} = Msig -1 {0...k} - Msig {0...k}
i=i+1
1738
y
1730
Mdiff[i]>0 && delta_av>0
or
Mdiff[i]<0 && delta_av<0
n
ir=ir+1
1732
y
1734
1744
| Mdiff[i] | > |delta_av|
n
ir = 0
ir <= Nr
y
1736
y
1740
y
Msig[i]= Msig -1 [i]
Msig[i]=Msig[i] - delta_av
n
Msig -1 {0...k} = Msig {0...k}
1722
Output
Msig -1 {0...k}
1724
END

FIG. 17B

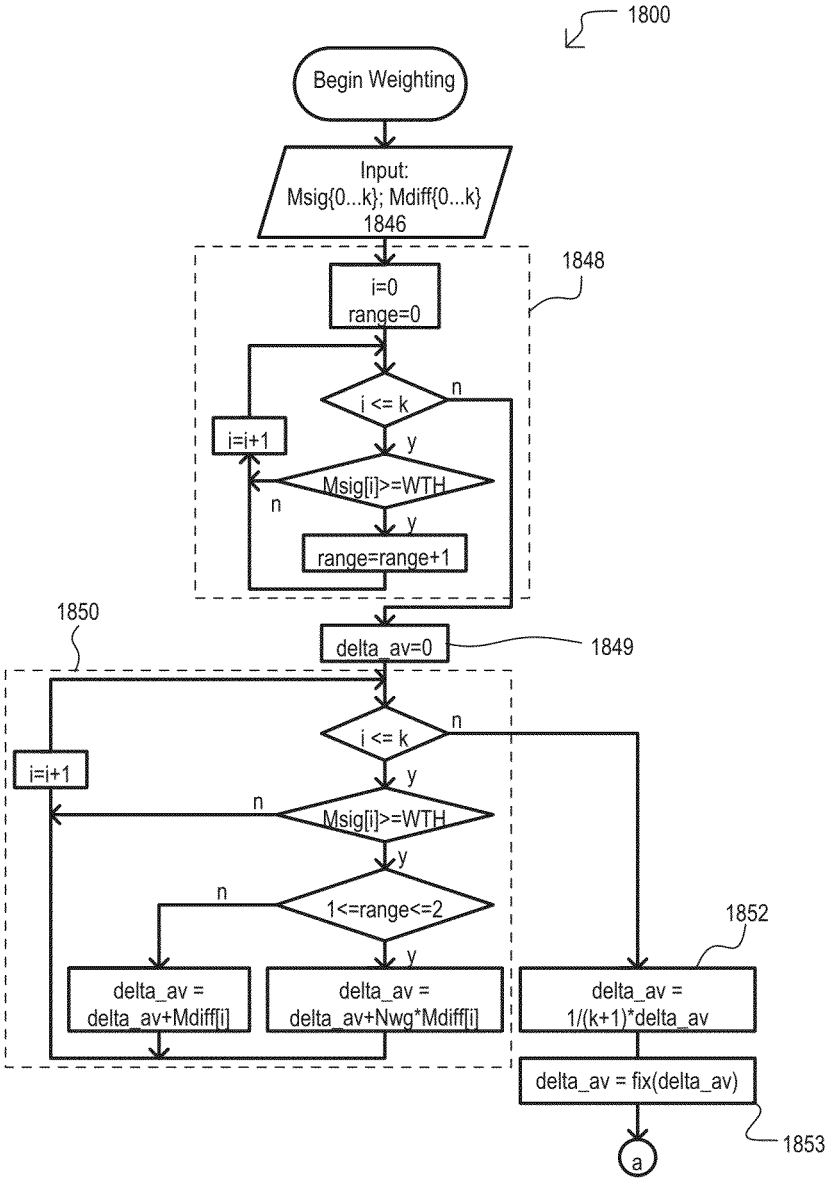

1800
Begin Weighting
Input:
Msig{0...k}; Mdiff{0...k}
1846
1848
i=0
range=0
i <= k
n
y
i=i+1
Msig[i]>=WTH
n
y
range=range+1
1850
delta_av=0
1849
i <= k
n
y
i=i+1
n
Msig[i]>=WTH
y
n
1<=range<=2
y
1852
delta_av =
delta_av+Mdiff[i]
delta_av =
delta_av+Nwg*Mdiff[i]
delta_av =
1/(k+1)*delta_av
delta_av = fix(delta_av)
1853
a

FIG. 18A

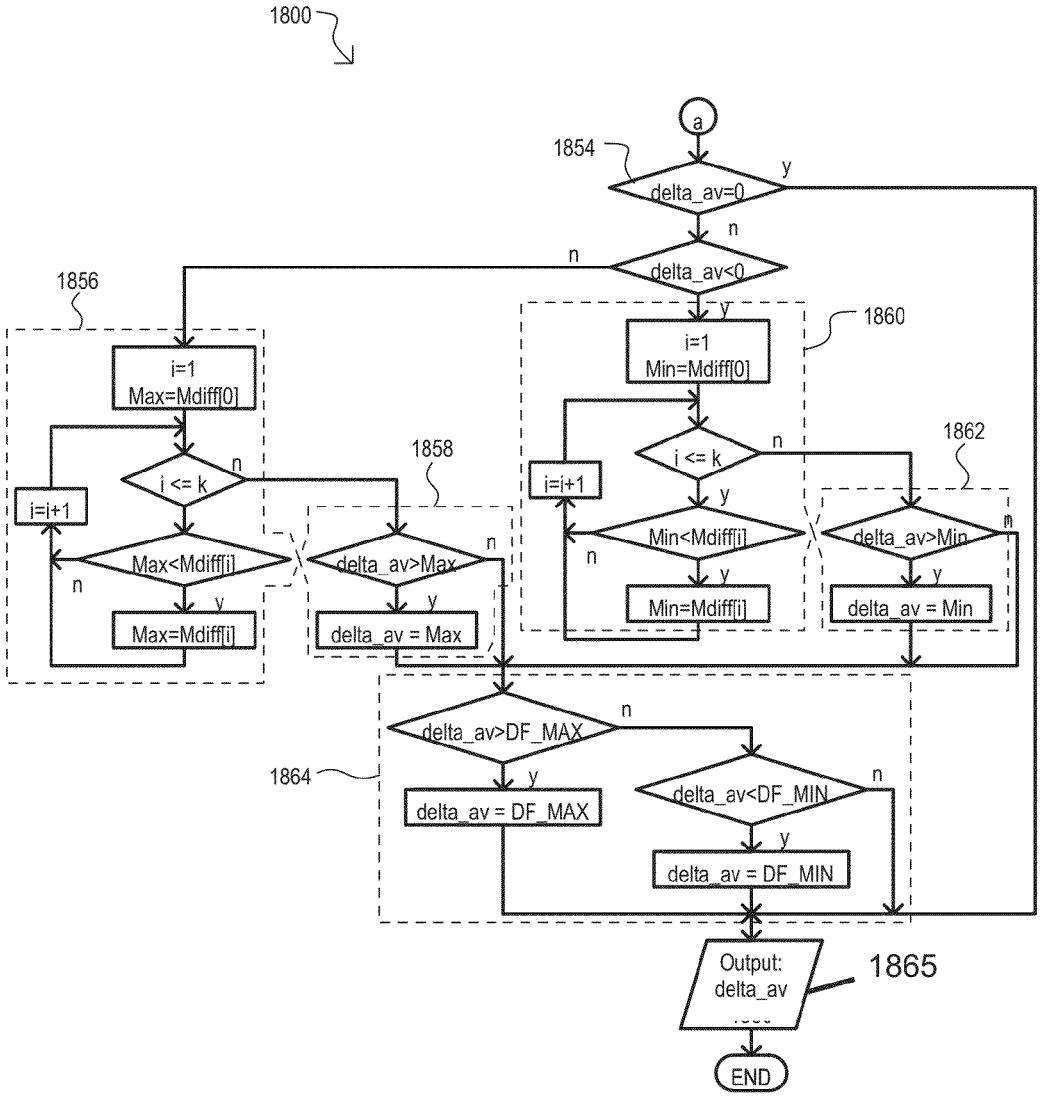

1800
a
1854
delta_av=0
y
n
delta_av<0
n
y
1856
1860
i=1
Max=Mdiff[0]
i=1
Min=Mdiff[0]
1858
1862
i <= k
n
i <= k
n
i=i+1
y
i=i+1
Max<Mdiff[i]
n
delta_av>Max
n
Min<Mdiff[i]
n
delta_av>Min
n
y
y
y
y
Max=Mdiff[i]
delta_av = Max
Min=Mdiff[i]
delta_av = Min
delta_av>DF_MAX
n
1864
y
delta_av<DF_MIN
n
delta_av = DF_MAX
y
delta_av = DF_MIN
Output:
delta_av
1865
END

FIG. 18B

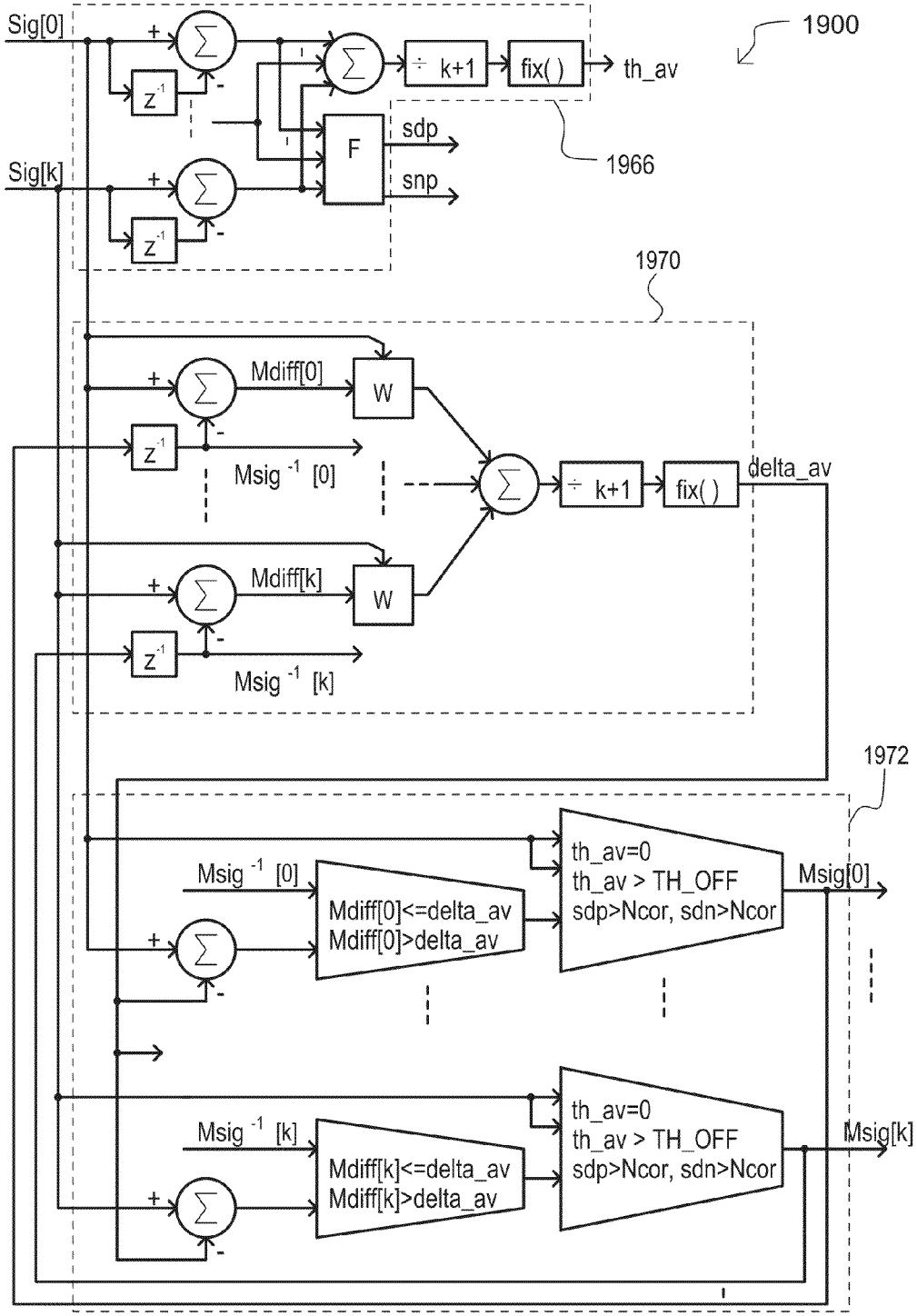

1900
Sig[0]
Sig[k]
z-1
÷ k+1
fix( )
th_av
F
sdp
snp
1966
1970
Mdiff[0]
W
Msig -1 [0]
Mdiff[k]
Msig -1 [k]
delta_av
1972
th_av=0
th_av > TH_OFF
sdp>Ncor, sdn>Ncor
Msig[0]
Mdiff[0]<=delta_av
Mdiff[0]>delta_av
Mdiff[k]<=delta_av
Mdiff[k]>delta_av
Msig[k]

FIG. 19

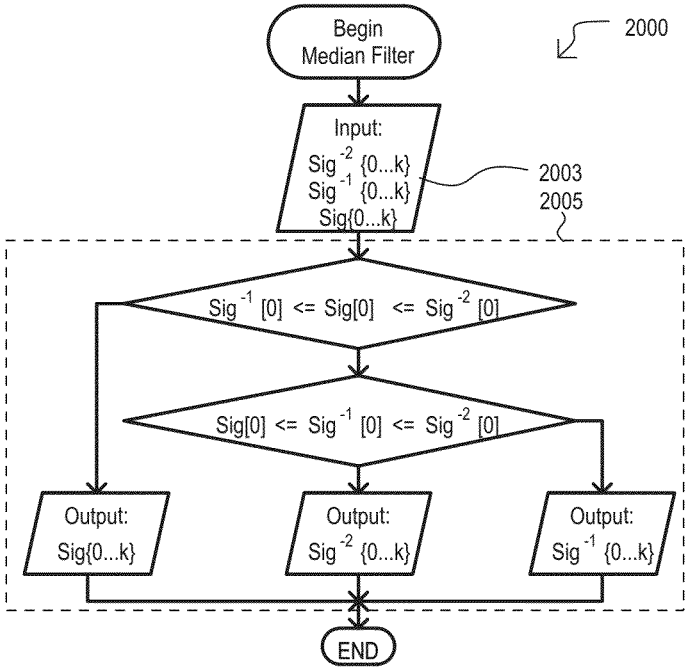

Begin
Median Filter
2000
Input:
Sig -2 {0...k}
Sig -1 {0...k}
Sig{0...k}
2003
2005
Sig -1 [0] <= Sig[0] <= Sig -2 [0]
Sig[0] <= Sig -1 [0] <= Sig -2 [0]
Output:
Sig{0...k}
Output:
Sig -2 {0...k}
Output:
Sig -1 {0...k}
END

FIG. 20

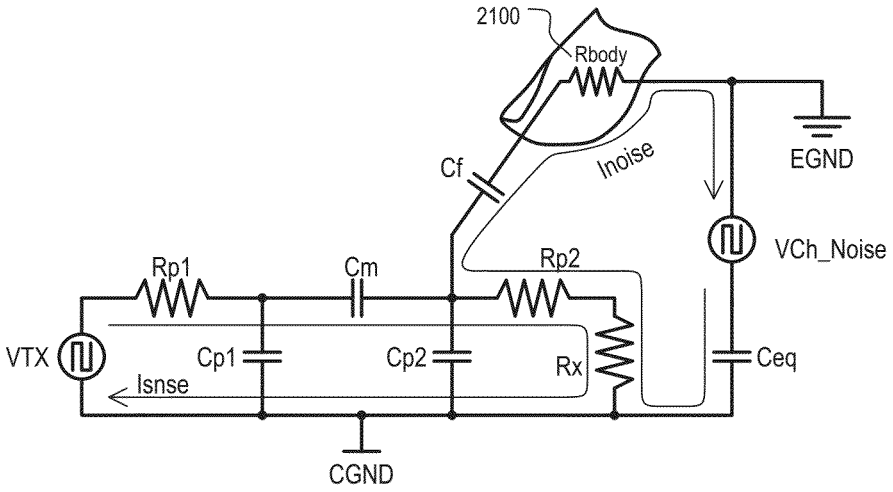


FIG. 21 (BACKGROUND)

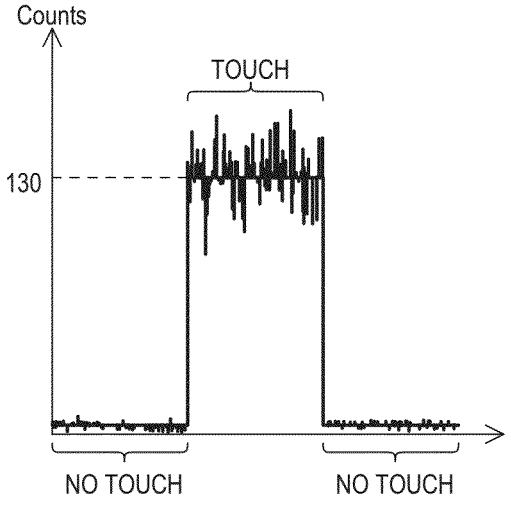


FIG. 22 (BACKGROUND)

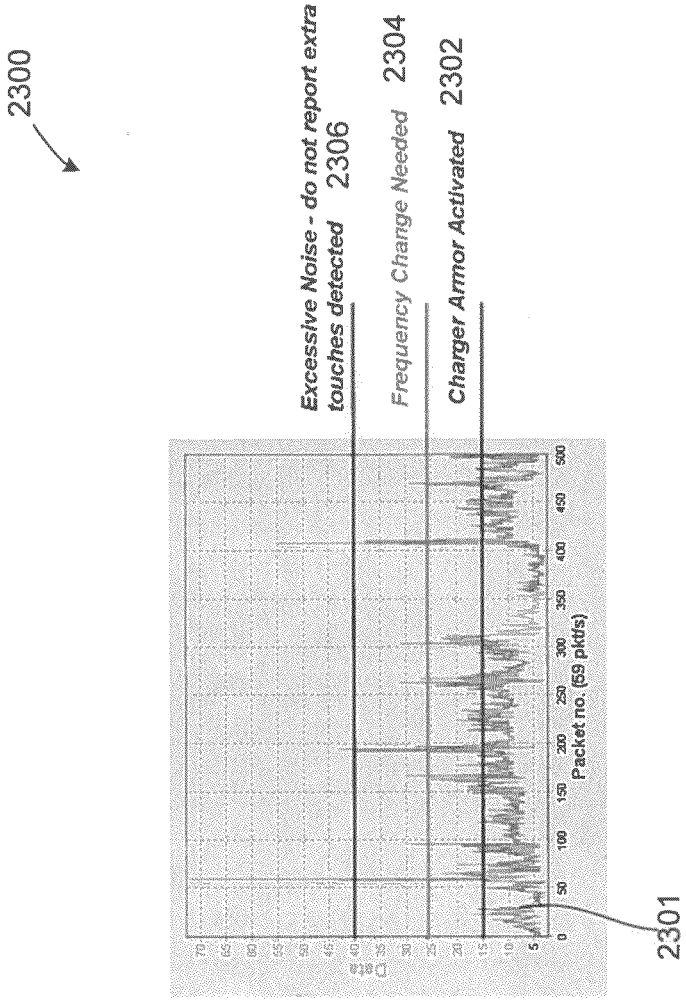

2300
Excessive Noise - do not report extra touches detected 2306
Frequency Change Needed 2304
Charger Armor Activated 2302
Data
Packet no. (59 pkt/s)
2301

FIG. 23

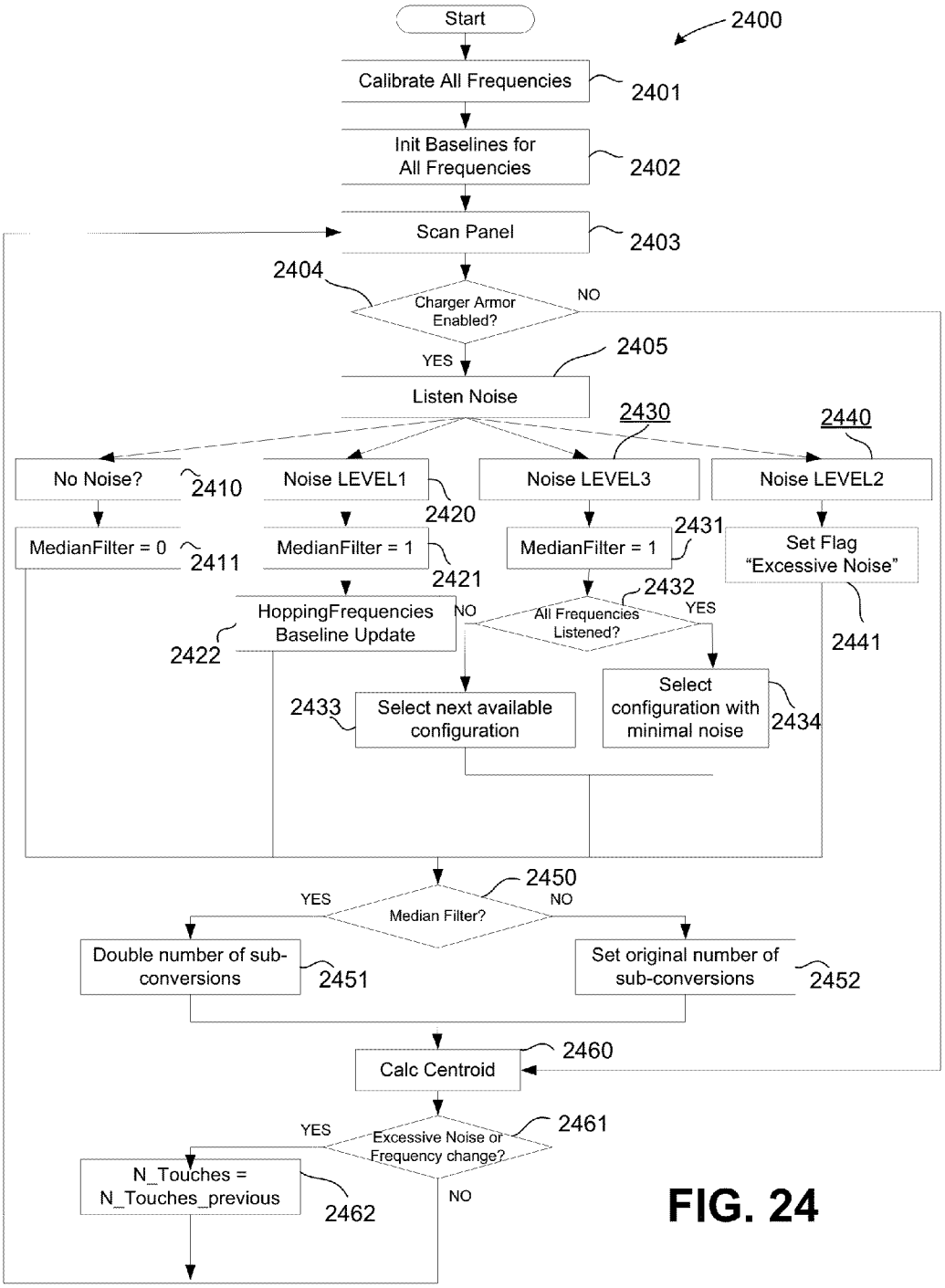

Start
2400
Calibrate All Frequencies
2401
Init Baselines for All Frequencies
2402
Scan Panel
2403
2404
Charger Armor Enabled?
NO
YES
2405
Listen Noise
2430
2440
No Noise?
2410
Noise LEVEL1
2420
Noise LEVEL3
Noise LEVEL2
MedianFilter = 0
2411
MedianFilter = 1
2421
MedianFilter = 1
2431
Set Flag "Excessive Noise"
2441
HoppingFrequencies Baseline Update
2422
2432
All Frequencies Listened?
NO
YES
2433
Select next available configuration
Select configuration with minimal noise
2434
2450
Median Filter?
YES
NO
Double number of sub-conversions
2451
Set original number of sub-conversions
2452
Calc Centroid
2460
2461
Excessive Noise or Frequency change?
YES
NO
N_Touches = N_Touches_previous
2462

FIG. 24

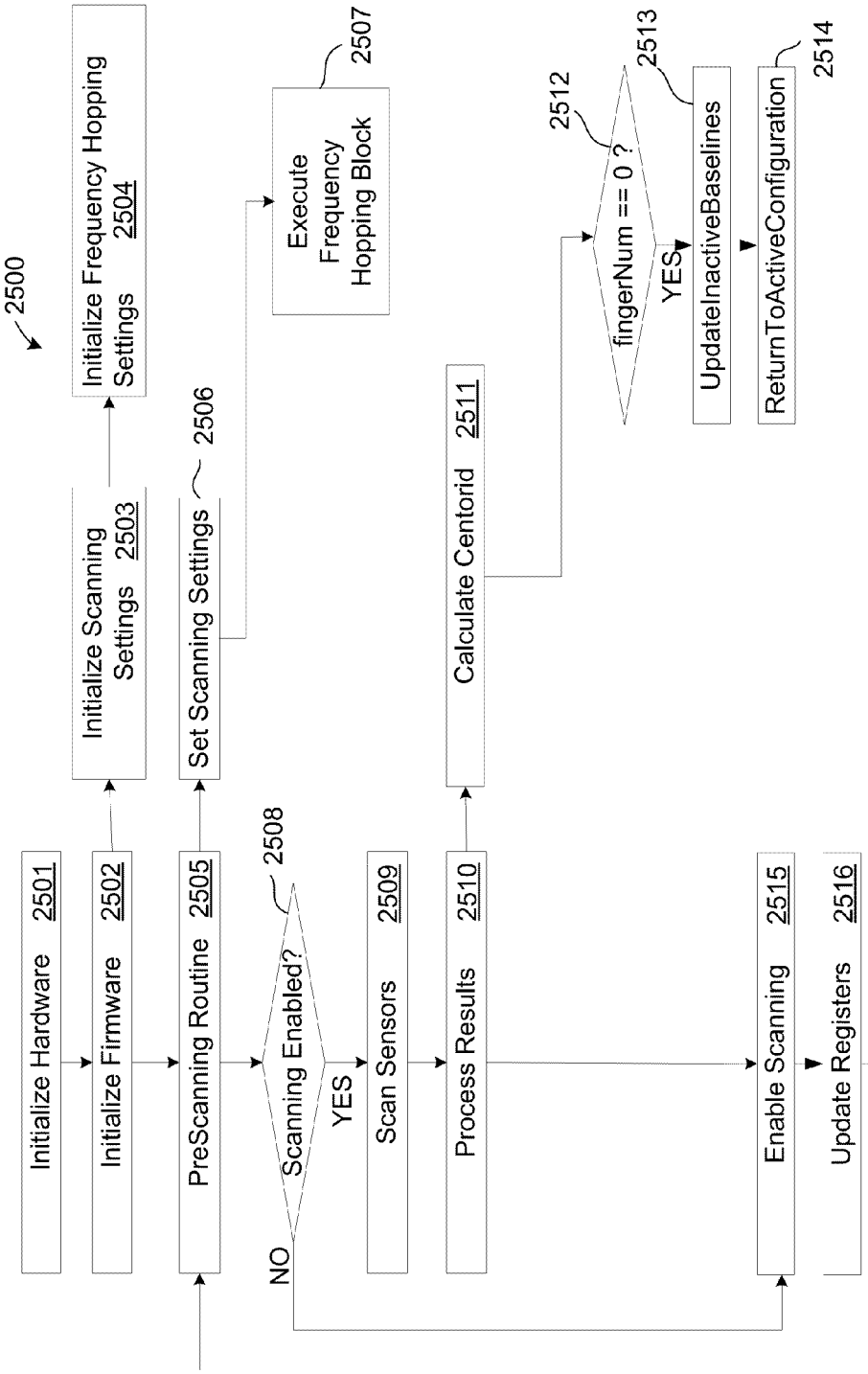

2500
Initialize Hardware 2501
Initialize Firmware 2502
Initialize Scanning Settings 2503
Initialize Frequency Hopping Settings 2504
PreScanning Routine 2505
Set Scanning Settings 2506
Execute Frequency Hopping Block 2507
Scanning Enabled? 2508
YES
NO
Scan Sensors 2509
Process Results 2510
Calculate Centorid 2511
fingerNum == 0 ? 2512
YES
UpdateInactiveBaselines 2513
ReturnToActiveConfiguration 2514
Enable Scanning 2515
Update Registers 2516
Report Data to Host 2517

FIG. 25

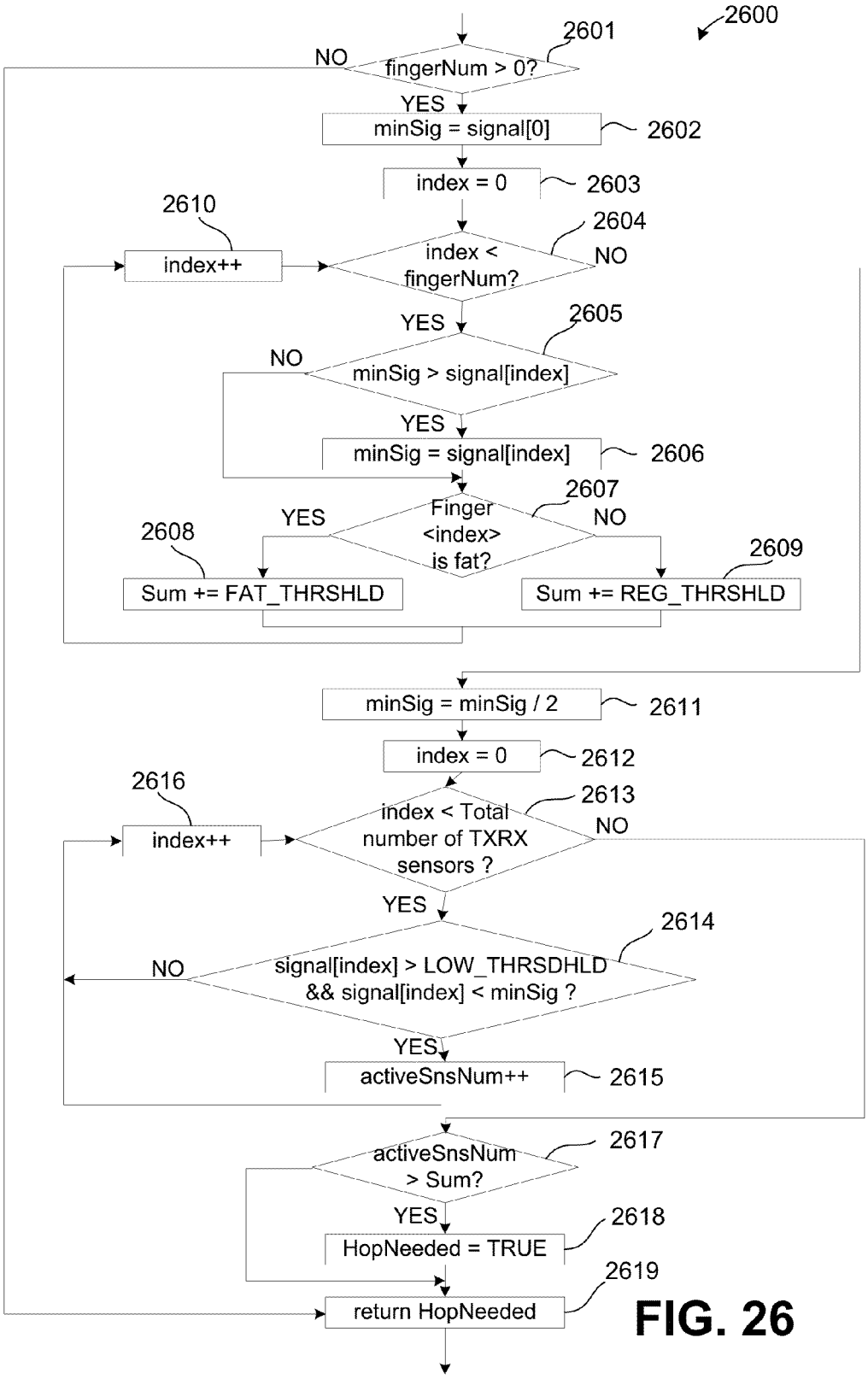

2600
2601
fingerNum > 0?
NO
YES
minSig = signal[0]
2602
index = 0
2603
2610
index++
2604
index < fingerNum?
NO
YES
2605
minSig > signal[index]
NO
YES
minSig = signal[index]
2606
2607
Finger <index> is fat?
YES
NO
2608
Sum += FAT_THRSHLD
2609
Sum += REG_THRSHLD
minSig = minSig / 2
2611
index = 0
2612
2616
index++
2613
index < Total number of TXRX sensors ?
NO
YES
2614
signal[index] > LOW_THRSDHLD && signal[index] < minSig ?
NO
YES
activeSnsNum++
2615
2617
activeSnsNum > Sum?
YES
2618
HopNeeded = TRUE
2619
return HopNeeded

FIG. 26

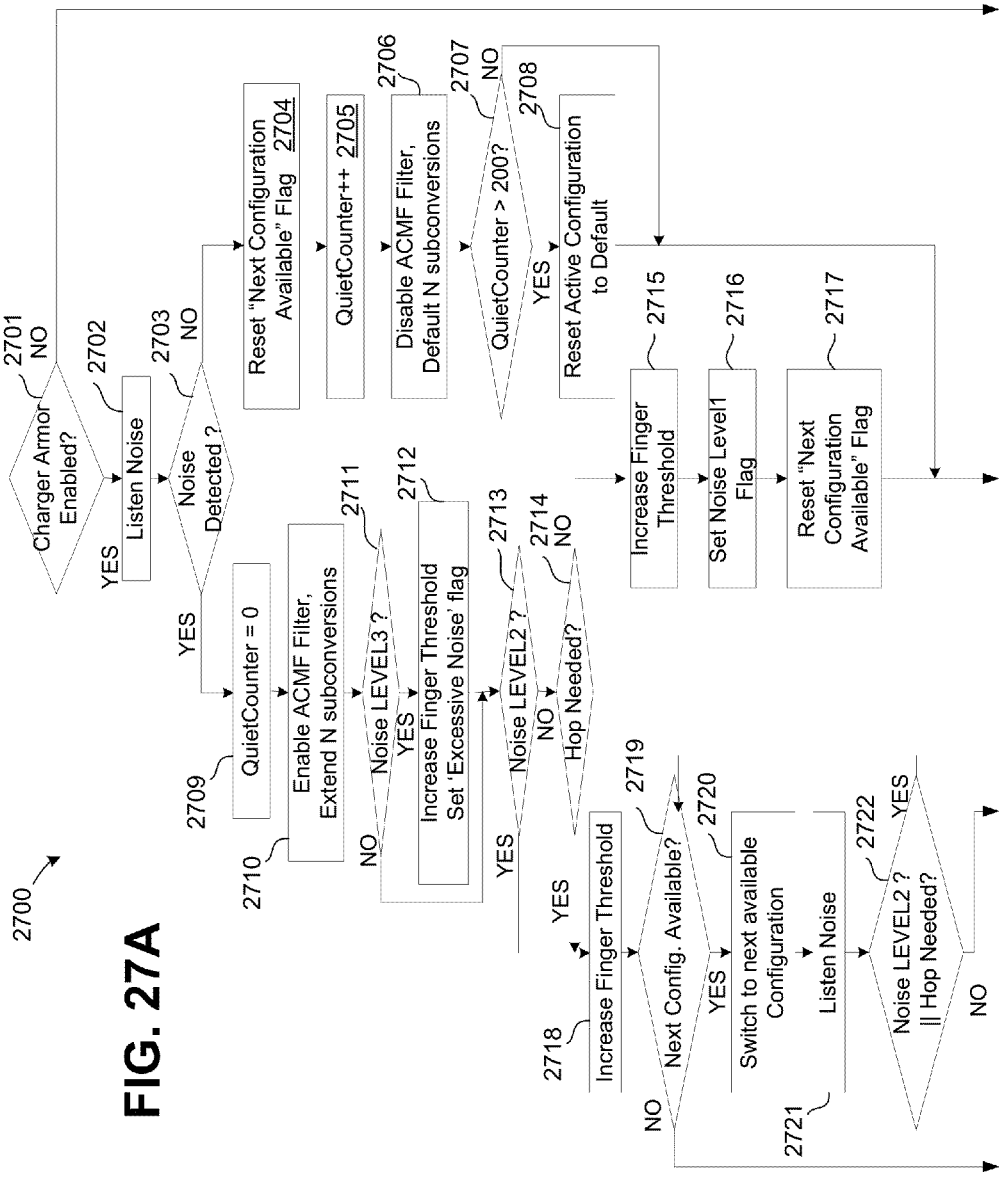

2700
2701
Charger Armor Enabled?
NO
YES
2702
Listen Noise
2703
Noise Detected ?
NO
YES
2704
Reset "Next Configuration Available" Flag
2705
QuietCounter++
2706
Disable ACMF Filter, Default N subconversions
2707
QuietCounter > 200?
NO
YES
2708
Reset Active Configuration to Default
2709
QuietCounter = 0
2710
Enable ACMF Filter, Extend N subconversions
2711
Noise LEVEL3 ?
NO
YES
2712
Increase Finger Threshold Set 'Excessive Noise' flag
2713
Noise LEVEL2 ?
YES
2714
Hop Needed?
NO
YES
2715
Increase Finger Threshold
2716
Set Noise Level1 Flag
2717
Reset "Next Configuration Available" Flag
2718
Increase Finger Threshold
2719
Next Config. Available?
NO
YES
2720
Switch to next available Configuration
2721
Listen Noise
2722
Noise LEVEL2 ? || Hop Needed?
YES
NO

FIG. 27A

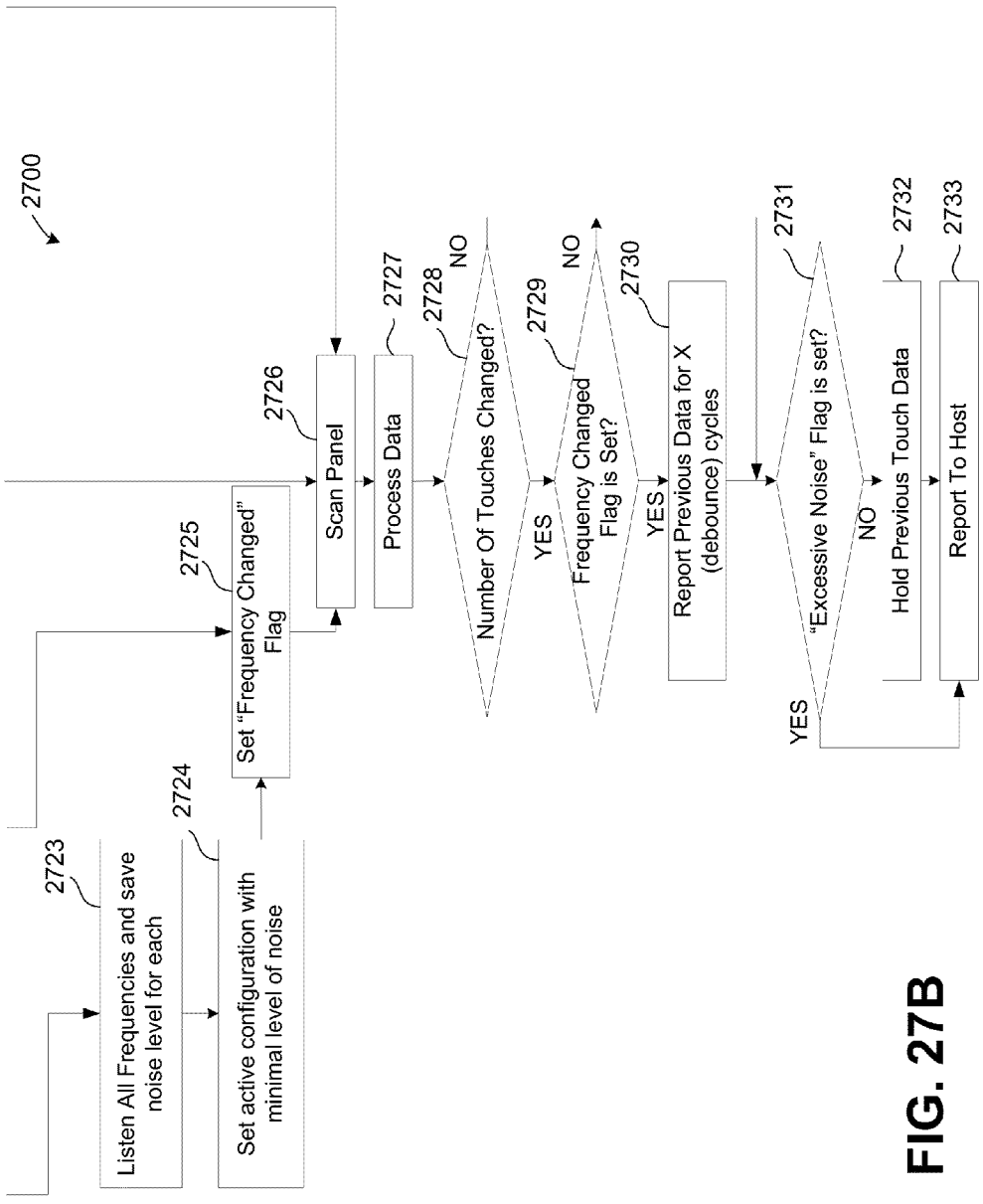
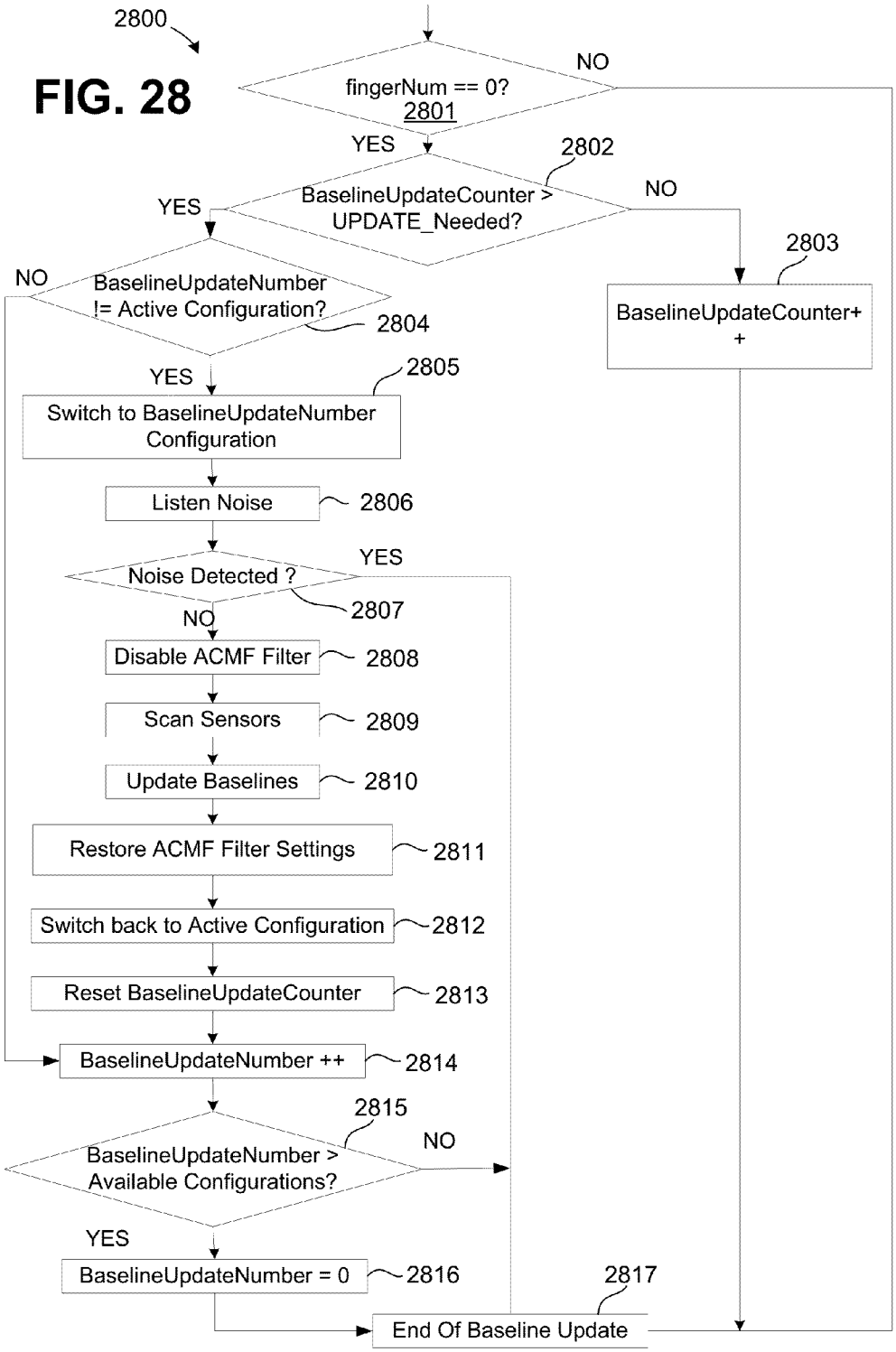

2700
2723
Listen All Frequencies and save noise level for each
2724
Set active configuration with minimal level of noise
2725
Set "Frequency Changed" Flag
2726
Scan Panel
2727
Process Data
2728
Number Of Touches Changed?
NO
YES
2729
Frequency Changed Flag is Set?
NO
YES
2730
Report Previous Data for X (debounce) cycles
2731
"Excessive Noise" Flag is set?
NO
YES
2732
Hold Previous Touch Data
2733
Report To Host

FIG. 27B

FIG. 28


2800
fingerNum == 0?
2801
NO
YES
2802
BaselineUpdateCounter > UPDATE_Needed?
NO
YES
2803
BaselineUpdateCounter++
NO
BaselineUpdateNumber != Active Configuration?
2804
YES
2805
Switch to BaselineUpdateNumber Configuration
Listen Noise
2806
Noise Detected ?
YES
2807
NO
Disable ACMF Filter
2808
Scan Sensors
2809
Update Baselines
2810
Restore ACMF Filter Settings
2811
Switch back to Active Configuration
2812
Reset BaselineUpdateCounter
2813
BaselineUpdateNumber ++
2814
2815
BaselineUpdateNumber > Available Configurations?
NO
YES
BaselineUpdateNumber = 0
2816
2817
End Of Baseline Update

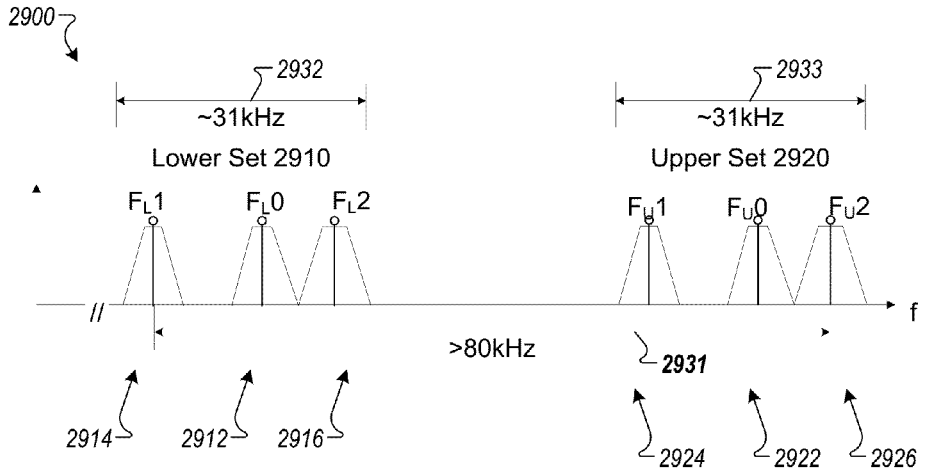

2900
2932
~31kHz
2933
~31kHz
Lower Set 2910
Upper Set 2920
F_L1
F_L0
F_L2
F_U1
F_U0
F_U2
f
>80kHz
2931
2914
2912
2916
2924
2922
2926

FIG. 29

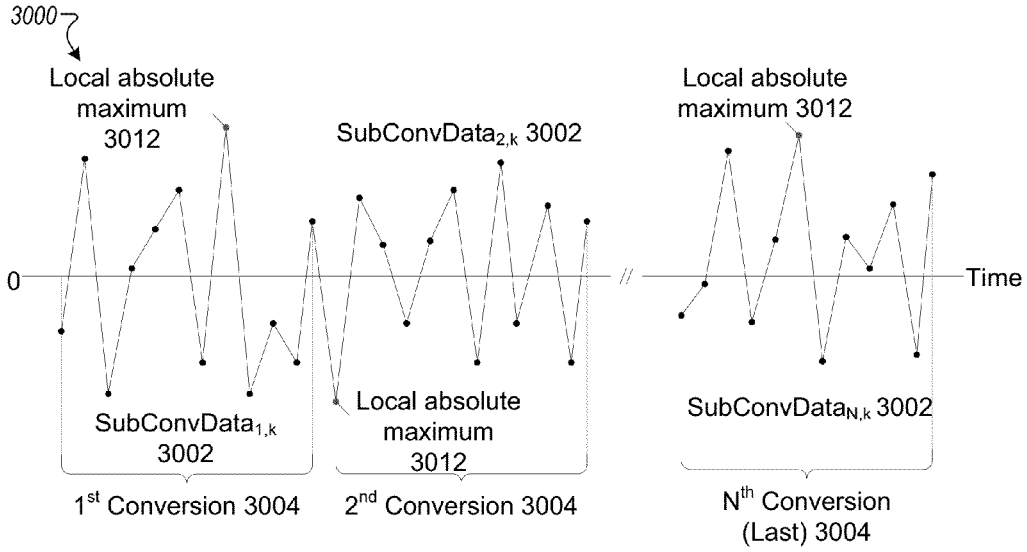

3000
Local absolute maximum 3012
SubConvData$_{2,k}$ 3002
Local absolute maximum 3012
0
Time
SubConvData$_{1,k}$ 3002
Local absolute maximum 3012
SubConvData$_{N,k}$ 3002
1st Conversion 3004
2nd Conversion 3004
Nth Conversion (Last) 3004

FIG. 30

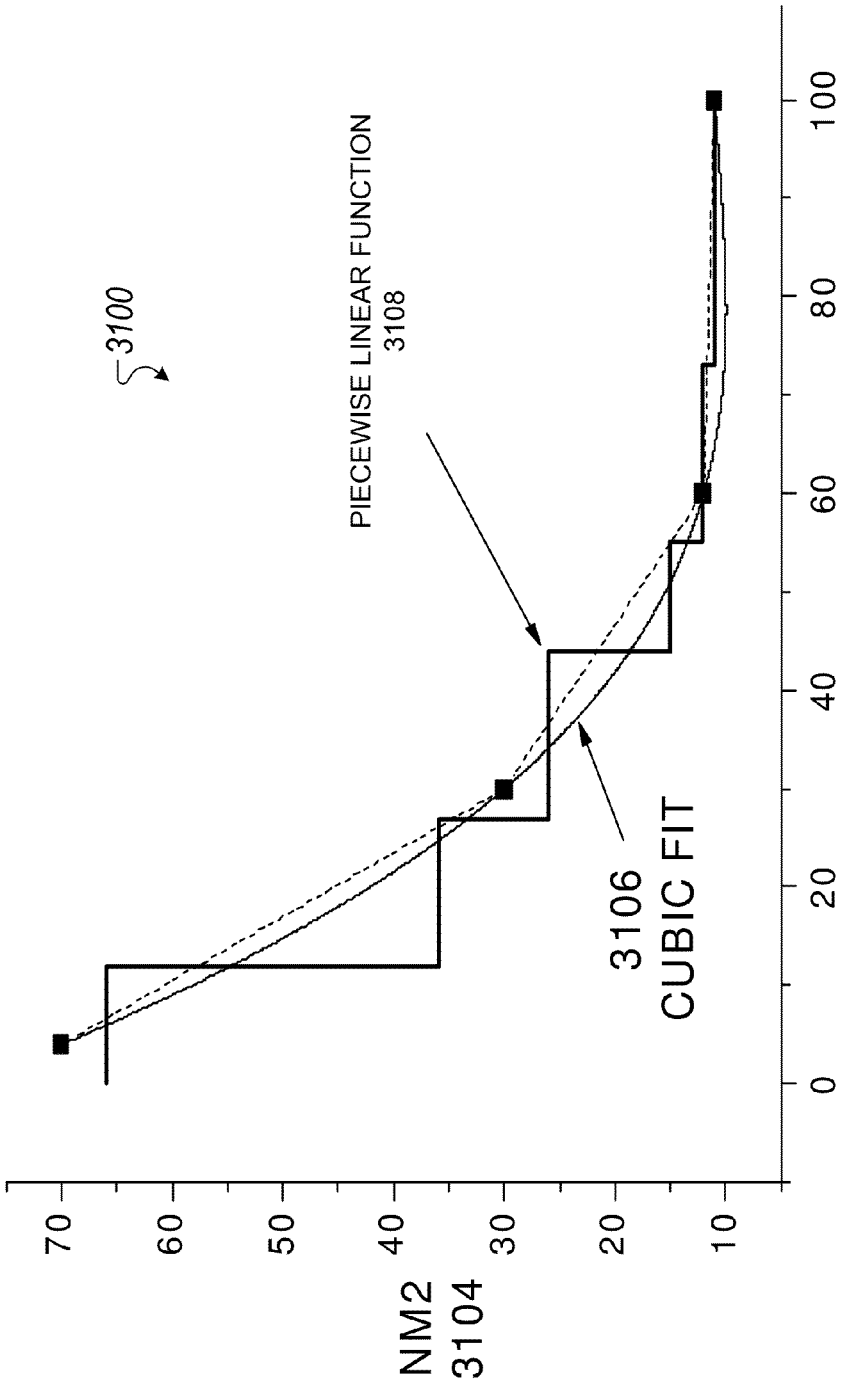

3100
PIECEWISE LINEAR FUNCTION
3108
3106
CUBIC FIT
NM2
3104
NM1
3102
70
60
50
40
30
20
10
0
20
40
60
80
100

FIG. 31

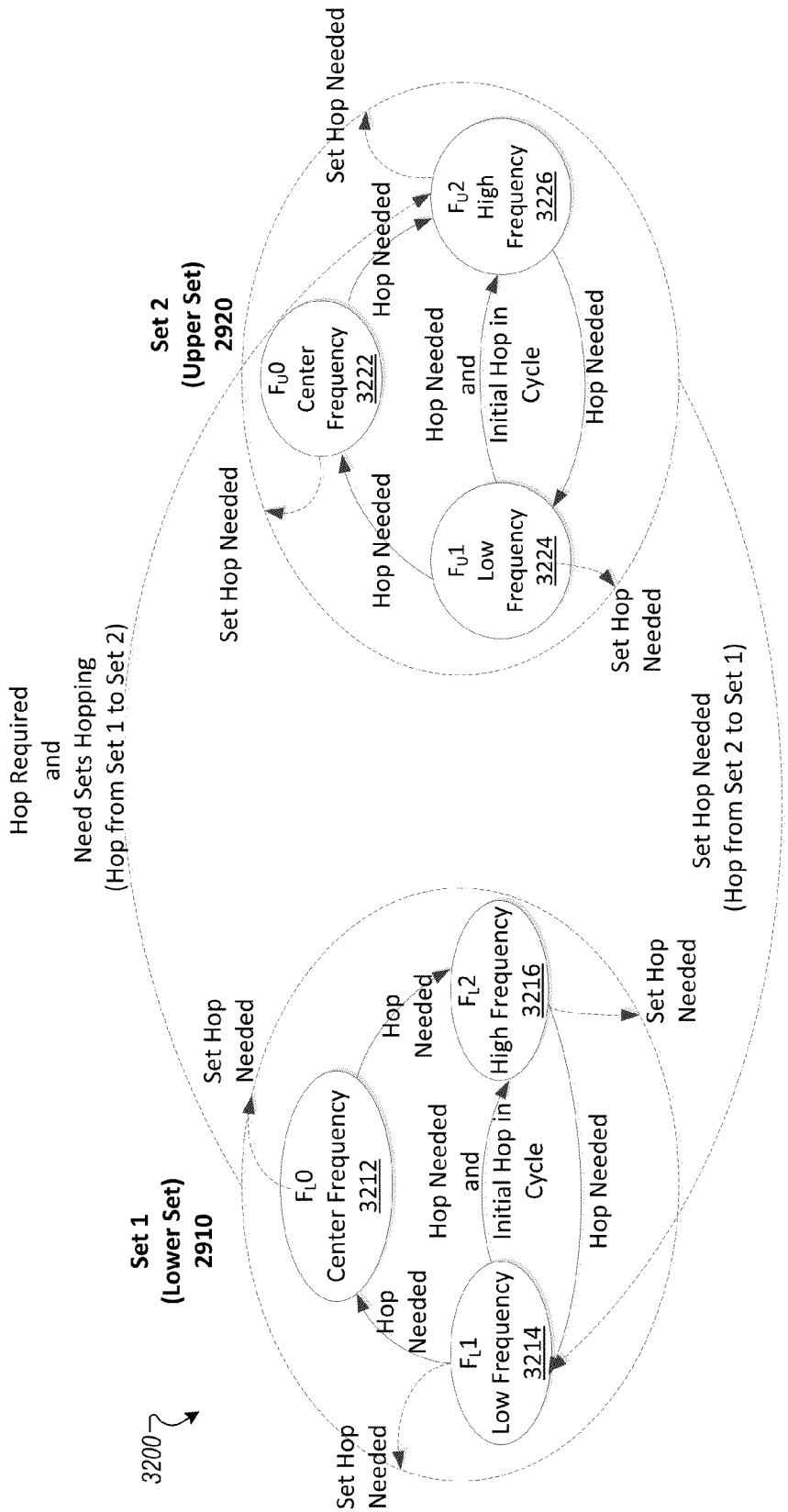

3200
Set 1
(Lower Set)
2910
Set 2
(Upper Set)
2920
Hop Required
and
Need Sets Hopping
(Hop from Set 1 to Set 2)
Set Hop Needed
(Hop from Set 2 to Set 1)
F_L0
Center Frequency
3212
F_L1
Low Frequency
3214
F_L2
High Frequency
3216
F_U0
Center
Frequency
3222
F_U1
Low
Frequency
3224
F_U2
High
Frequency
3226
Hop
Needed
Hop Needed
and
Initial Hop in
Cycle
Set Hop
Needed

FIG. 32

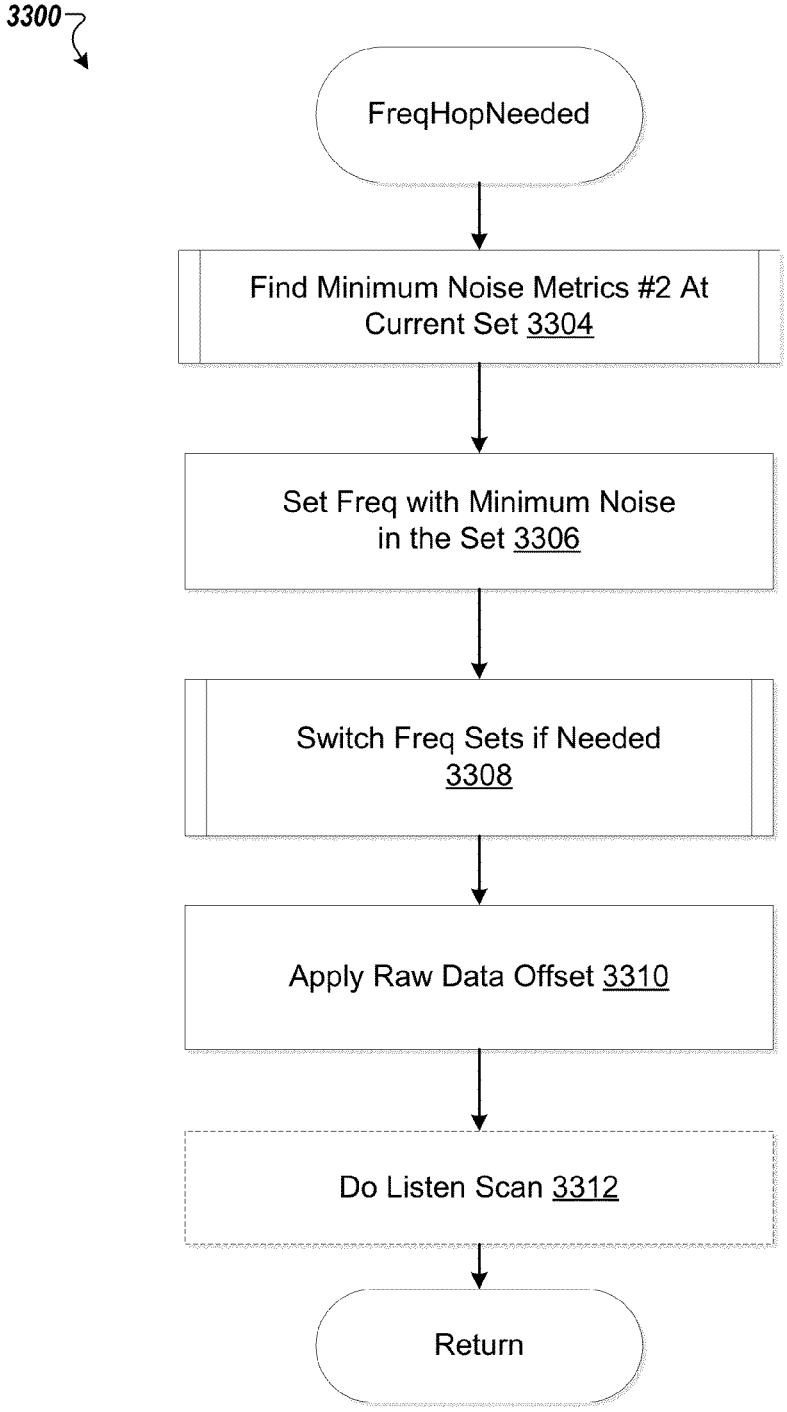

3300
FreqHopNeeded
Find Minimum Noise Metrics #2 At Current Set 3304
Set Freq with Minimum Noise in the Set 3306
Switch Freq Sets if Needed 3308
Apply Raw Data Offset 3310
Do Listen Scan 3312
Return

FIG. 33

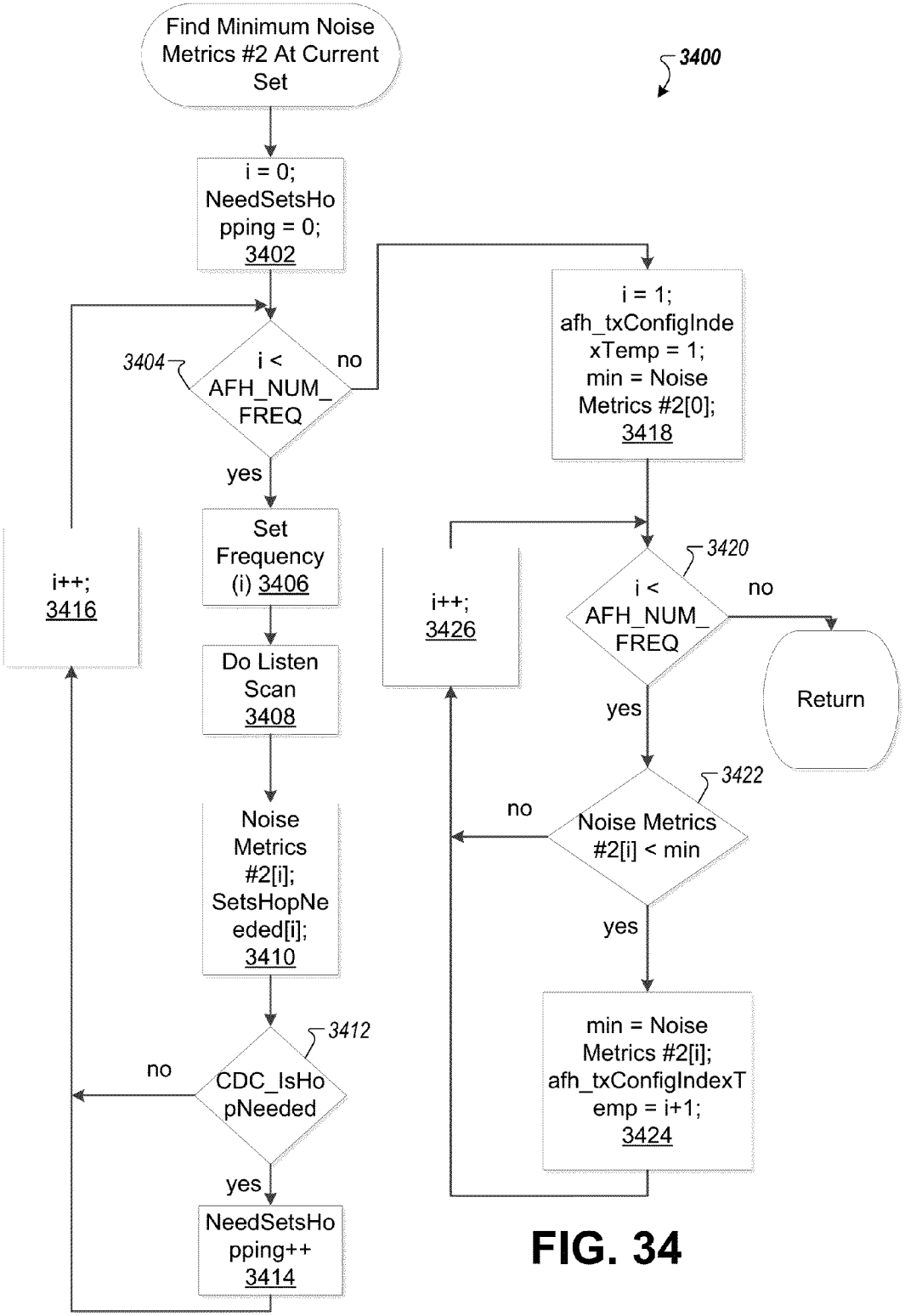

Find Minimum Noise Metrics #2 At Current Set
3400
i = 0; NeedSetsHopping = 0; 3402
3404
i < AFH_NUM_FREQ
no
yes
Set Frequency (i) 3406
Do Listen Scan 3408
Noise Metrics #2[i]; SetsHopNeeded[i]; 3410
3412
CDC_IsHopNeeded
no
yes
NeedSetsHopping++ 3414
i++; 3416
i = 1; afh_txConfigIndexTemp = 1; min = Noise Metrics #2[0]; 3418
3420
i < AFH_NUM_FREQ
no
yes
Return
3422
Noise Metrics #2[i] < min
no
yes
min = Noise Metrics #2[i]; afh_txConfigIndexTemp = i+1; 3424
i++; 3426

FIG. 34

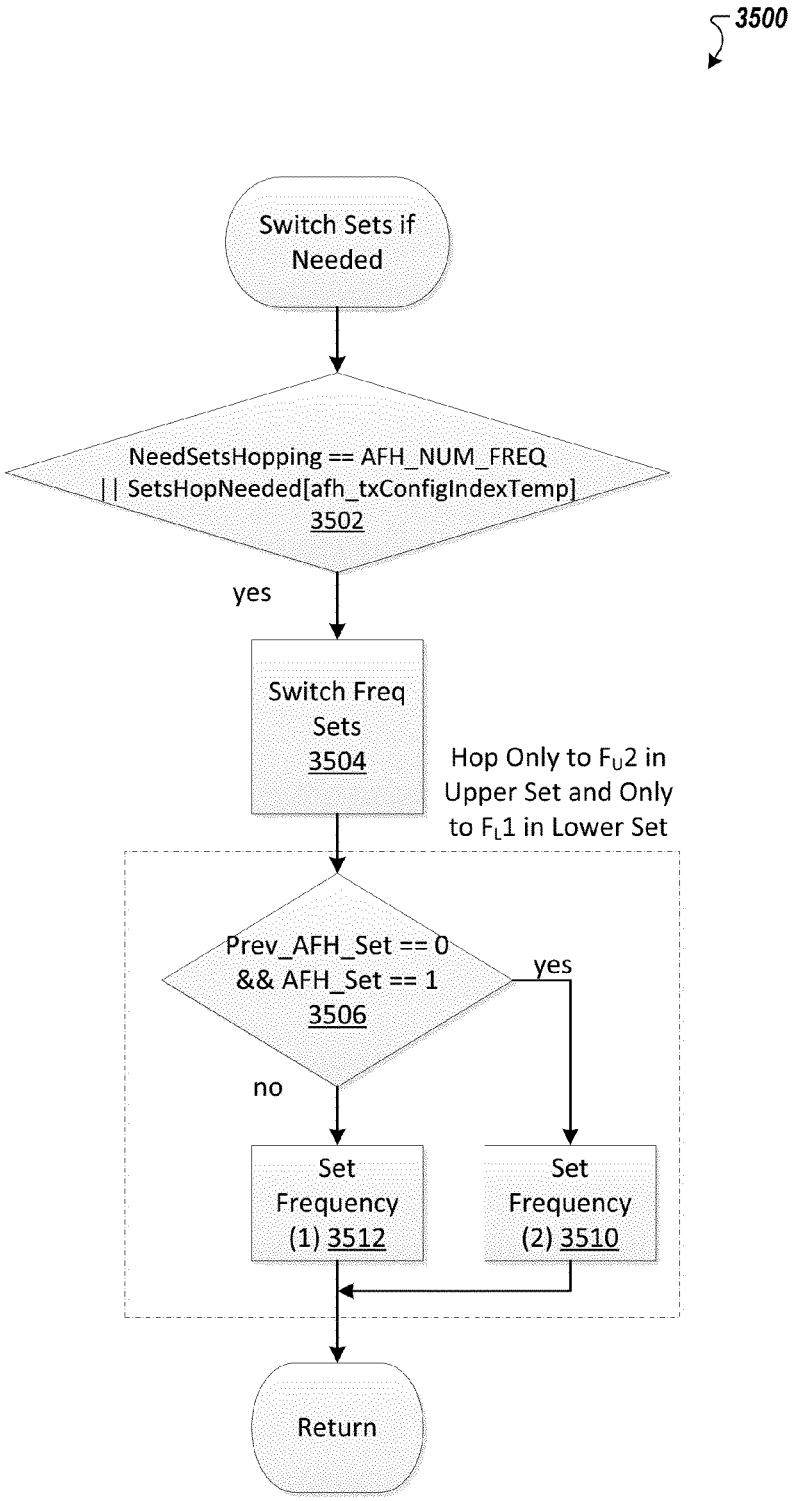

3500
Switch Sets if Needed
NeedSetsHopping == AFH_NUM_FREQ || SetsHopNeeded[afh_txConfigIndexTemp]
3502
yes
Switch Freq Sets
3504
Hop Only to F_U2 in Upper Set and Only to F_L1 in Lower Set
Prev_AFH_Set == 0 && AFH_Set == 1
3506
yes
no
Set Frequency (1) 3512
Set Frequency (2) 3510
Return

FIG. 35

FREQUENCY SELECTION WITH TWO FREQUENCY SETS OF MULTIPLE OPERATING FREQUENCIES IN A MUTUAL CAPACITANCE SENSING DEVICES

RELATED APPLICATIONS

This application is a continuation-in-part application of U.S. patent application Ser. No. 13/429,869, filed Mar. 26, 2012, which claims the benefit of U.S. Provisional Application No. 61/602,750, filed Feb. 24, 2012, the entire contents of both are hereby incorporated by reference. This application also claims the benefit of U.S. Provisional Application No. 61/677,651, filed Jul. 31, 2012, the entire contents of which is hereby incorporated by reference.

TECHNICAL FIELD

The present disclosure relates generally to capacitance sensing systems, and more particularly to noise filtering in such systems.

BACKGROUND

Capacitance sensing systems can sense electrical signals generated on electrodes that reflect changes in capacitance. Such changes in capacitance can indicate a touch event (i.e., the proximity of an object to particular electrodes). Electrical sense signals can be degraded by the presence of noise.

Noise in capacitance sensing systems can be conceptualized as including "internal" noise and "external noise". Internal noise can be noise that can affect an entire system at the same time. Thus, internal noise can appear on all electrodes at the same time. That is, internal noise can be a "common" mode type noise with respect to the sensors (e.g., electrodes) of a system. Sources of internal noise can include, but are not limited to: sensor power supply noise (noise present on a power supply provided to the capacitance sensing circuit) and sensor power generation noise (noise arising from power generating circuits, such as charge pumps, that generate a higher magnitude voltage from a lower magnitude voltage).

In touchscreen devices (i.e., devices having a display overlaid with a capacitance sensing network), a display can give rise to internal noise. As but a few examples, display noise sources can include, but are not limited to: LCD VCOM noise (noise from a liquid crystal display that drives a segment common voltage between different values), LCD VCOM coupled noise (noise from modulating a thin film transistor layer in an LCD device that can be coupled through a VCOM node), and display power supply noise (like sensor power generation noise, but for power supplied of the display).

Common mode type noise can be addressed by a common mode type filter that filters out noise common to all electrodes in a sense phase.

External noise, unlike internal noise, can arise from charge coupled by a sensed object (e.g., finger or stylus), and thus can be local to a touch area. Consequently, external noise is typically not common to all electrodes in a sense phase, but only to a sub-set of the electrodes proximate to a touch event.

Sources of external noise can include charger noise. Charger noise can arise from charger devices (e.g., battery chargers that plug into AC mains, or those that plug into automobile power supplies). Chargers operating from AC mains can often include a "flyback" transform that can create an unstable device ground with respect to "true" ground (earth ground). Consequently, if a user at earth ground touches a capacitance sense surface of a device while the device is connected to a charger, due to the varying device ground, a touch can inject charge at a touch location, creating a localized noise event.

Other sources of external noise can arise from various other electrical fields that can couple to a human body, including but not limited to AC mains (e.g., 50/60 Hz line voltage), fluorescent lighting, brushed motors, arc welding, and cell phones or other radio frequency (RF) noise sources. Fields from these devices can be coupled to a human body, which can then be coupled to a capacitance sensing surface in a touch event.

FIG. **21** is a schematic diagram of model showing charger noise in a conventional mutual capacitance sensing device. A voltage source VTX can be a transmit signal generated on a TX electrode, Rp**1** can be a resistance of a TX electrode, Cp**1** can be (self) capacitance between a TX electrode and device ground (which can be a charger ground CGND), Cm can be a mutual capacitance between a TX electrode and a receive (RX) electrode, Cp**2** can be a self-capacitance of an RX electrode, Rp**2** can be a resistance of a RX electrode. Rx can represent an impedance of a capacitance sensing circuit.

Cf can be a capacitance between a sense object **2100** (e.g., finger). A voltage source VCh_Noise can represent noise arising from differences between CGND and earth ground (EGND). Voltage source VCh_Noise can be connected to a device ground by an equivalent capacitance Ceq.

As shown in FIG. **21**, a sense current (Isense) can be generated in response to source VTX that can vary in response to changes in Cm. However, at the same time, a noise current (Inoise) can arise a touch event, due to the operation of a charger. A noise current (Inoise) can be additive and subtractive to an Isense signal, and can give rise to erroneous sense events (touch indicated when no touch occurs) and/or erroneous non-sense events (touch not detected).

FIG. **22** shows capacitance sense values (in this case counts) corresponding to non-touch and touch events in a conventional system subject to external noise. As shown, while a device is not touched (NO TOUCH) noise levels are relatively small. However, while a device is touched (TOUCH) noise levels at the touch location are considerably higher.

While capacitance sensing systems can include common mode type filtering, such filtering typically does not address the adverse affects of external noise, as such noise is not present on all electrodes, but rather localized to electrodes proximate a sense event.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example, and not of limitation, in the figures of the accompanying drawings in which:

FIG. **1** is a flow diagram of a capacitance sensing operation according to an embodiment.

FIG. **2** is a flow diagram of a capacitance sensing operation according to another embodiment.

FIG. **3** is a block schematic diagram of a capacitance sensing system according to an embodiment.

FIG. **4** is a block schematic diagram of a capacitance sensing system having charger detection according to an embodiment.

FIG. **5** is a block schematic diagram of a capacitance sensing system having a display alarm according to an embodiment.

FIG. **6** is a block schematic diagram of a capacitance sensing system according to another embodiment.

FIG. **7** is a schematic diagram of a noise listening circuit according to an embodiment.

FIGS. **8**A and **8**B are plan views of a noise listening configurations for a mutual capacitance sense network according to embodiments.

FIGS. **9**A and **9**B are diagrams showing noise listening operations according to an embodiment.

FIG. **10** is a flow diagram of a noise listening operation according to an embodiment.

FIG. **11** is a flow diagram of a noise listening scan initialization operation according to an embodiment.

FIG. **12** is a flow diagram of a noise listening restore-to-normal operation according to an embodiment.

FIG. **13** is a flow diagram of a noise detection operation according to an embodiment.

FIG. **14** is a timing diagram showing a noise detection operation that can provide an alarm condition according to an embodiment.

FIG. **15** is a flow diagram of a local noise filtering operation according to an embodiment.

FIGS. **16**A and **16**B are plan views showing electrode selection for scaling in a filter operation according to an embodiment.

FIGS. **17**A and **17**B are flow diagrams of an adaptive jitter filter (AJF) according to an embodiment.

FIGS. **18**A and **18**B are flow diagrams of a weighting function that can be included in the AJF according to an embodiment.

FIG. **19** is a diagram showing an AJF operation another to an embodiment.

FIG. **20** is a flow diagram of a median filter that can be included in embodiments.

FIG. **21** is a schematic diagram showing charger noise in a conventional mutual capacitance sensing device.

FIG. **22** shows capacitance sense values with external noise corresponding to non-touch and touch events in a conventional system.

FIG. **23** is a graph of detected noise and three noise thresholds according to one embodiment.

FIG. **24** is a flow chart illustrating a method of noise suppression according to one embodiment.

FIG. **25** is a flow chart illustrating a method of noise suppression with frequency hopping according to one embodiment.

FIG. **26** is a flow chart that illustrates a method of forcing a frequency change according to one embodiment.

FIGS. **27**A and **27**B are a state machine for charger armor and frequency hopping according to one embodiment.

FIG. **28** is a flow chart that illustrates a method of an inactive baseline update according to one embodiment.

FIG. **29** is a graph illustrating two frequency sets of operating frequencies on a TX signal frequency axis according to one embodiment.

FIG. **30** is a graph illustrating sub-conversions of capacitance values measured during multiple conversions over time according to one embodiment.

FIG. **31** is a graph illustrating a non-linear dependence of a second noise metric (NM**2**) and a first noise metric (NM**1**) and a cubit fit of the same according to one embodiment.

FIG. **32** is a state diagram illustrating a first frequency switching technique according to an embodiment.

FIG. **33** is a flow chart illustrating a second frequency switching technique according to an embodiment.

FIG. **34** is a flow chart illustrating a method of determining a minimum NM**2** at a current set for the second frequency switching technique according to an embodiment.

FIG. **35** is a flow chart illustrating a method of determining if switching frequency sets is needed from the current set for the second frequency switching technique according to an embodiment.

DETAILED DESCRIPTION

In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known circuits, structures, and techniques are not shown in detail, but rather in a block diagram in order to avoid unnecessarily obscuring an understanding of this description.

Reference in the description to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The phrase "in one embodiment" located in various places in this description does not necessarily refer to the same embodiment.

Various embodiments will now be described that show capacitance sensing systems and methods that listen for noise and alter filtering of sensed values according to a noise level. In particular embodiments, if noise levels are below a certain threshold, indicating the absence of (or low levels of) external noise (i.e., noise localized to a touch area), sensed values can be filtered for common mode type noise. However, if noise levels are above the threshold, sensed valued can be filtered to account for external noise. In particular embodiments, filtering for localized noise can include a median filter.

In the embodiments below, like items are referred to by the same reference character but with the leading digit(s) corresponding to the figure number.

FIG. **1** shows a flow diagram of a capacitance sensing system operation **100** according to one embodiment. A system operation **100** can include a listening operation **102**, a no local noise processing path **104**, and a local noise processing path **106**. A listening operation **102** can monitor a sense network **108** for noise. A sense network **108** can include multiple electrodes for sensing a capacitance in a sensing area. In a particular embodiment, a sense network **108** can be a mutual capacitance sensing network having transmit (TX) electrodes that can be driven with a transmit signal, and receive (RX) electrodes coupled to the TX electrodes by a mutual capacitance.

In some embodiments, a listening operation **102** can use the same electrodes used for capacitance sensing (e.g., touch position detection) for noise detection. In a very particular embodiment, a listening operation **102** can monitor all RX electrodes for noise. In an alternate embodiment, a listening operation **102** can monitor all RX electrodes in a noise listening operation. In yet another embodiment, a listening operation **102** can monitor both TX and RX electrodes in a listening operation.

A listening operation **102** can compare detected noise to one or more threshold values to make a determination on the presence of noise. If noise is determined to be present (Noise), a local noise processing path **106** can be followed. In contrast, if no noise is determined to be present (No Noise), a no local noise processing path **104** can be followed.

Processing paths **104** and **106** show how sense signals derived from sense network **108** can be acquired and filtered. A no local noise processing path **104** can acquire sense values from a sense network **108** with a standard scan **110** and

non-local filtering **112**. A standard scan **110** can sample electrode values to generate sense values using a set number of sample operations and/or a set duration. Non-local filtering **112** can provide filtering that is not directed at local noise events, such as those arising from external noise. In particular embodiments, non-local filtering **112** can include common mode type filtering that filters for noise common to all sense electrodes.

A local noise processing path **106** can address the adverse affects of local noise, like that arising from external noise. A local noise processing path **106** can acquire sense values from a sense network **108** with an extended scan **114** and local filtering **116**. An extended scan **114** can sample electrode values with a larger number of sample operations and/or a longer duration than the standard scan **110**. In addition, local filtering **116** can provide filtering to remove local noise events, such as those arising from external noise. In particular embodiments, local filtering **116** can include median filtering.

In this way, in response to the detection of noise, a processing of capacitance sense signals can switch from a standard scan time and non-local filtering to an increased scan time and local filtering.

FIG. **2** shows a flow diagram of a capacitance sensing system operation **200** according to another embodiment. In one particular embodiment, system operation **200** can be one implementation of that shown in FIG. **1**. In addition to items like those shown in FIG. **1**, FIG. **2** further shows a noise alarm operation **218** and touch position calculation operation **220**.

In the embodiment shown, a listening operation **202** can include listener scanning **222**, listener common mode filtering (CMF) **224**, and noise detection **226**. Listener scanning **222** can include measuring signals on multiple electrodes of sense network **208**. Scanning (noise signal acquisition) times can be selected based on sense network and expected noise source(s). A listener CMF **224** can filter for noise common to all electrodes being scanned. Such filtering can enable external type noise (noise local to a subset of the scanned electrodes) to pass through for noise detection **226**.

Noise detection **226** can establish whether any detected noise exceeds one or more thresholds. In the embodiment shown, if noise is below a first threshold, noise detection **226** can activate a "No Noise" indication. If noise is above a first threshold, noise detection **226** can activate a "Noise" indication. If noise is above a second threshold, greater than the first threshold, noise detection **226** can activate a "High Noise" indication.

In the case of a "No Noise" indication, processing can proceed according to no local noise processing path **204**. Such a processing path **204** can utilize a standard scanning **210**, which in the particular embodiment shown can include 8 sub-conversions per electrode. A sub-conversion can be an elementary signal conversion event, and can reflect demodulation and/or integration results for one or more full input signal periods. Such processing can further include a CMF filtering **212** of values sensed on multiple electrodes. Such values can then be subject to baseline and difference calculations **228**, which can determine and difference between current sense values and baseline values. A sufficiently large difference can indicate a touch event.

In the case of a "Noise" indication, processing can proceed according to local noise processing path **206**. Local noise processing **206** can increase signal acquisition time with an extended scanning **214** that utilizes 16 sub-conversion (i.e., doubles a scanning time versus the no noise case). A processing path **206** can further include non-CMF filtering **216** that can filter for external noise events affecting a local set of electrodes. In the particular embodiment shown, non-CMF filtering **216** can include median filtering **216-0** and non-linear filtering **216-1**. Resulting filtered sense values can then be subject to baseline and difference calculations **228**, like that described for the no local noise processing path **204**.

In the case of a "High Noise" indication, processing can include activation of an alarm indication **218**. An alarm indication **218** can inform a user and/or a system that noise levels are high enough to result in erroneous capacitance sensing results. In a very particular embodiment, such a warning can be a visual warning on a display associated with the sense network **208** (e.g., a touchscreen display). However, warnings may include various other indication types, including but not limited to: a different type of visual alarm (e.g., LED), an audio alarm, or a processor interrupt, to name just a few. In the embodiment of FIG. **2**, in response to a "High Noise" indication, processing may also proceed according to local noise processing path **206**. However, in other embodiments, capacitance sense processing could be interrupted, or additional filtering or signal boosting could occur.

Operation **200** can also include touch position calculations **220**. Such actions can derive positions of touch events from sense values generated by processing paths **204** and **206**. Touch position values generated by calculations **220** can be provided to a device application, or the like.

In this way, a listening circuit can include common mode filtering of sense electrodes to listen for localized noise events, such as external noise from a device charger or the like. Sense signals can be filtered based on sensed noise values and/or an alarm can be triggered if noise levels exceed a high threshold value.

Referring now to FIG. **3**, a capacitance sensing system according to an embodiment is shown in a block schematic diagram and designated by the general reference character **300**. A system **300** can include a sense network **308**, switch circuits **332**, an analog-to-digital converter (ADC) **334**, a signal generator **336**, and a controller **330**. A sense network **308** can be any suitable capacitance sense network, including a mutual capacitance sensing network, as disclosed herein. A sense network **308** can include multiple sensors (e.g., electrodes) for sensing changes in capacitance.

Switch circuits **332** can selectively enable signal paths, both input and output signal paths, between a sense network **308** and a controller **330**. In the embodiment shown, switch circuits **332** can also enable a signal path between a signal generator **336** and sense network **308**.

An ADC **334** can convert analog signals received from sense network **308** via switching circuits **308** into digital values. An ADC **334** can be any suitable ADC, including but not limited to a successive approximation (SAR) ADC, integrating ADC, sigma-delta modulating ADC, and a "flash" (voltage ladder type) ADC, as but a few examples.

A signal generator **336** can generate a signal for inducing sense signals from sense network **308**. As but one example, a signal generator **336** can be a periodic transmit (TX) signal applied to one or more transmit electrodes in a mutual capacitance type sense network. A TX signal can induce a response on corresponding RX signals, which can be sensed to determine whether a touch event has occurred.

A controller **330** can control capacitance sensing operations in a system **300**. In the embodiment shown, a controller can include sense control circuits **338**, filter circuits **311**, position determination circuits **320**, and noise listening circuits **302**. In some embodiments, controller **330** circuits (e.g., **338**, **311**, **320** and **302**) can be implemented by a processor executing instructions. However, in other embodiments, all or a portion of such circuits can be implemented by custom logic and/or programmable logic.

Sense control circuits **338** can generate signals for controlling acquisition of signals from sense network **308**. In the embodiment shown, sense control circuits **338** can activate switch control signals SW_CTRL applied to switching circuits **332**. In a particular embodiment, mutual capacitance sensing can be employed, and sense control circuits **338** can sequentially connect a TX signal from signal generator **336** to TX electrodes within sense network **308**. As each TX electrode is driven with the TX signal, sense control circuits **338** can sequentially connect RX electrodes to ADC **334** to generate digital sense values for each RX electrode. It is understood that other embodiments can use different sensing operations.

Noise listening circuits **302** can also control acquisition of signals from sense network **308** by activating switch control signals SW_CTRL. However, noise listening circuit **302** can configure paths to sense network **308** to enable the detection of local noise, as opposed to touch events. In a particular embodiment, noise listening circuit **302** can isolate signal generator **336** from sense network **308**. In addition, multiple groups of electrodes (e.g., RX, TX or both) can be simultaneously connected to ADC **334**. Noise listener **302** can filter such digital values and then compare them to noise thresholds to determine a noise level. Such actions can include arriving at "No Noise", "Noise" and optionally "High Noise" determinations as described for FIG. **2**.

In response to a noise determination from noise listening circuit **302**, a controller **330** can alter capacitance sensing operations. In one embodiment, if noise is detected, signal acquisition times can be increased (e.g., sub-conversions increased) and filtering can be changed (e.g., median filtering instead of common mode filtering).

Filter circuits **311** can filter sense values generated during sense operations and noise detection operations. In the embodiment shown, filter circuits **311** can enable one or more types of median filtering **316** and one or more types of CMF **312**. It is understood that filter circuits can be digital circuits operating on digital values representing sensed capacitance. In a particular embodiment, filter circuits **311** can include a processor creating sense value data arrays from values output from ADC **334**. These arrays of sense values can be manipulated according to one or more selected filtering algorithm to create an output array of filtered sense values. A type of filtering employed by filter circuits **311** can be selected based on detected noise levels.

Position determination circuits **320** can take filtered sense values to generate touch position values (or no detected touches) for use by other processes, such as applications run by a device.

In this way, a capacitance sensing system can include listening circuits for detecting noise values and digital filters, selectable based on a detected noise level.

Referring now to FIG. **4**, a capacitance sensing system according to another embodiment is shown in a block schematic diagram and designated by the general reference character **400**. In the embodiment of FIG. **4**, a noise listening operation can vary based on a system condition. In the particular embodiment shown, noise listening can be enabled or disabled based on the presence of a charger.

A system **400** can include sections like those of FIG. **3**, and such sections can have the same or equivalent structures as FIG. **3**. FIG. **4** differs from FIG. **3** in that it also shows a charger interface **440**, battery interface **448**, power control circuits **441**, and application(s) **446**.

A charger interface **440** can enable power to be provided to system **400** that charges a battery via a battery interface **448**. In some embodiments, a charger interface **440** can be a physical interface that creates a mechanical connection between a charger **442** and the system **400**. In a particular embodiment, such a physical connection can include a ground connection that can give rise to injected current as represented in FIG. **22**. However, alternate embodiments can include wireless charging interfaces.

Power control circuits **441** can activate a charging indication (Charging) when a charger **442** is coupled to a system **400**, and thus can present an external noise source. In addition, power control circuits **441** can control charging operations of a battery via batter interface **448**.

Referring still to FIG. **4**, listening circuits **402'** can vary listening operations in response to a charger indication (Charging). In one embodiment, if the Charging indication is inactive, indicating that a charger **442** is not present, listening circuits **402'** can be disabled. If the Charging indication is active, listening circuits **402'** can be enabled. However in other embodiments, listening circuits **402'** can switch between different types of listening operations based on a charger indication (Charging).

It is understood that while a charger can be one source of noise, other types of power supplies for a device can be a source of noise (e.g., AC/DC converters within such devices). For example, some devices can be connected to a computer with its own external power supply, or even a charger within an automobile.

Application(s) **446** can be programs executable by a system **400** utilizing position values from position determination circuits **420**.

In this way, a capacitance sensing system can vary listening circuit operations that detect noise values based on a physical condition of the system.

Referring now to FIG. **5**, a capacitance sensing system according to a further embodiment is shown in a block schematic diagram and designated by the general reference character **500**. In the embodiment of FIG. **5**, an alarm can be generated when noise exceeds a threshold value.

A system **500** can include sections like those of FIG. **3**, and such sections can have the same or equivalent structures as FIG. **3**. FIG. **5** differs from FIG. **3** in that is also shows an alarm circuit **518**, a display **548** and application(s) **546**.

A listening circuit **502** can provide a noise level indication to alarm circuit **518** when detected noise is determined to exceed a high threshold. An alarm circuit **518** can activate one or more alarms, when the noise threshold is exceeded. In the very particular embodiment shown, alarm circuit **518** can provide an alarm (Alarm-Display) to display **548**. In response to such an alarm, a display **548** can show a visual alarm indicating that touch inputs are affected by noise (e.g., touch inputs will not be accepted, etc.). In one particular embodiment, display **548** and sense network **508** can be a touchscreen assembly (i.e., sense network **508** is physically overlaid on display **548**).

In some embodiments, an alarm circuit **518** can provide an alarm to application(s) **546**. Such applications can then alter execution and/or generate their own alarm. Further, as noted in conjunction with FIG. **2**, an alarm can take various other forms (e.g., an interrupt, or the like).

In this way, a capacitance sensing system can generate an alarm for a user in the event noise levels exceed a predetermined threshold.

Referring now to FIG. **6**, a capacitance sensing system according to another embodiment is shown in a block schematic diagram and designated by the general reference character **600**. The embodiment of FIG. **6** shows an implementation utilizing a processor and instructions to provide listening, selectable filtering, and alarm functions.

A system **600** can include switching circuits **632**, controller **630**, a capacitance sense system **678**, oscillator circuits **650**, an ADC **634**, instruction memory **660**, communication circuits **656**, random access memory (RAM) **658**, and a power control circuits **644**.

Switching circuits **632** can provide analog signal paths between a sense network **608** and circuits within a system **600**. In the embodiment shown, switching circuits **632** can include a number of channels **664-0** to **-7** and a channel multiplexer (MUX) **672**. Switching and MUXing operations within switching circuits **632** can be controlled by switch control signals (SW_CTRL) provided by controller **630**. Each channel (**664-0** to **-7**) can include a number of input/output (I/O) switches (one shown **666**) connected to an I/O connection **631**, an I/O MUX **668**, and a sample and hold (S/H) circuit **670**. Each I/O switch (**666**) can connect a corresponding I/O **631** to a RX path (one shown as **674**) or a TX path (one shown as **676**). I/O MUX **668** can connect one of RX paths **674** within a channel to the corresponding S/H circuit **670**. TX paths **676** can receive a TX signal. A channel MUX **672** can selectively connect a S/H circuit **670** within each channel (**664-0** to **-7**) to ADC **634**.

An ADC **634** can include any suitable ADC as described herein, or an equivalent.

FIG. **6** shows a system **600** connected to mutual capacitance sense network **608**. Sense network **608** can include TX electrodes formed by TX plates (one shown as **608-0**) and RX plates (one shown as **608-1**). By operation of switching circuits **632**, TX electrodes can be connected to a TX path **676**, while multiple RX electrodes are connected to corresponding RX paths **674**.

In the embodiment of FIG. **6**, a controller **630** can include a processor **630-0** and digital processing circuits **630-1**. A processor **630-0** can control operations of digital processing circuits **630-1** in response to instructions stored in instruction memory **660**. Instruction memory **660** can include noise listening instructions **602**, alarm control instructions **618**, and filter instructions **611**. Filter instructions **611** can include multiple filtering operations, and in the embodiment shown, can include median filter instructions **616** and CMF instructions **612**.

In response to noise listening instructions **602**, a controller **630** can generate signals that connect multiple I/Os **631** to ADC **634**. In one embodiment, values can be subject to an initial listening CMF operation. Such an operation can be called from filter instructions **611** or be built into noise listening instructions **602**. Resulting values can then be compared to one or more thresholds to determine a noise level. If a noise level exceeds a certain level, a listening circuit **602** can establish capacitance sensing parameters directed to filtering local noise (e.g., an external noise source). In some embodiments, such parameters can include those described for other embodiments, including an increased scan time and/or non-common mode (e.g., median) filtering. In addition, if a noise threshold level is above another certain level, alarm instructions **618** can be called to generate an appropriate alarm.

Processor **630-0** alone, or in combination with digital processing circuits **630-1**, can perform arithmetic and logic operations for detecting noise and/or filtering sense values.

Capacitance sensing system **678** can include circuits for performing capacitance sensing operations. In some embodiments, capacitance sensing system **678** can include sense control circuits **638** that generate switch control signals for controlling switching circuits **632**. In one embodiment, capacitance sensing system **678** can perform sensing operation based on criteria established by controller **630**. In a particular embodiment, a controller **630** can vary a sensing time (e.g., number of sub-conversions) based on a noise level.

Referring still to FIG. **6**, oscillator circuits **650** can generate signals for controlling timing of operations within system **600**. In one embodiment a TX signal presented at TX paths **676** can be provided by, or derived from signals generated by oscillator circuits **650**.

Communication circuits **656** can provide capacitance sensing results to other systems or circuits of a device containing the capacitance sensing system **600**. RAM **658** can be provided to enable processor **630-0** to execute arithmetic operations and/or temporarily store instruction data. In particular embodiments, a RAM **658** can store sense value matrices that are manipulated by processor **630-0** to detect noise and/or filter capacitance sense values.

Power control circuits **644** can generate power supply voltages for various portions within a system **600**. In some embodiments, power control circuits **644** provide a charging indication, like that described for FIG. **4**, which can indicate when a charger is coupled to the system **600**. A processor **630-0** can then bypass noise listening instructions **602** in the absence of a charger, or may select between multiple listening algorithms based on the presence or absence of a charger.

FIG. **6** also shows timer circuits **652** and programmable circuits **654**. Timer circuits **652** can provide timing functions for use by various sections of system **600**. Programmable circuits **654** can be programmed with configuration data to perform custom function. In the embodiment shown, programmable circuits **654** can include programmable digital blocks.

In a very particular embodiment, a system **600** can be implemented with the PSoC® 3 type programmable system-on-chip developed by Cypress Semiconductor Corporation of San Jose, Calif. U.S.A.

In this way, a capacitance sensing system can include a processor that can execute any of: noise listening instructions, noise alarm instructions, median filtering, and CMF.

FIG. **7** is a schematic diagram showing a noise listening configuration for a mutual capacitance sense network **708** according to an embodiment. A sense network **708** can include first electrodes (one shown as **780**) and second electrodes (one shown as **782**) coupled to one another by a mutual capacitance Cm. Noise, represented by noise voltage source **784**, on one or more first electrodes **780** can induce a noise signal (Ix) by mutual capacitance coupling. In a very particular embodiment, first electrodes **780** can be TX electrodes and second electrodes **782** can be RX electrodes. However, the TX electrodes are not driven by any system generated TX signal, but rather are used to detect noise.

FIGS. **8**A and **8**B show different noise listening configurations according to embodiments.

FIG. **8**A shows a noise listening configuration for a mutual capacitance sense network **808** according to one embodiment. Sense network **808** can include TX electrodes (one highlighted as **880**) arranged in one direction and RX electrodes (one highlighted as **882**) arranged in another direction. In the embodiment shown, sets of RX electrodes **882** (in this embodiment, sets of two) can be connected to RX paths (RX**0** to RX**7**) for noise listening operations. TX electrodes **880** can be connected to ground.

FIG. **8**B shows a noise listening configuration for a mutual capacitance sense network **808** according to another embodiment. Sense network **808** can have the structure shown in FIG. **8**A. However, RX electrodes **882** and TX electrodes **880** can be commonly connected to a same RX path. In the particular embodiment shown, RX paths RX**0** to RX**3** can be connected to two RX electrodes **882** and one TX electrode

880, while RX paths RX4 to RX7 can be connected to two RX electrodes 882 and two TX electrodes 880.

In this way, RX and/or TX electrodes of a mutual capacitance sense network can be connected to capacitance sensing inputs to listen for noise while a TX signal is prevented from being applied to the network.

FIGS. 9A and 9B show listening operations according to embodiments.

FIG. 9A shows a listening operation 900-A having serial noise listening operations. Progression of time is shown by arrow "t". A listening operation 900-A can begin with a listening scanning action 902. Such an action can include acquiring capacitance values across multiple sensors (e.g., electrodes). In particular embodiments, such a step can include establishing connections to a mutual capacitance sense array like that shown in FIG. 8A or 8B. Following a listening scanning 902, acquired values can be subject to listening CMF 904. A listening CMF 904 can include common mode filtering that can filter out noise common to all electrodes and thus help isolate local noise (e.g., external type noise). Filtered sense values can then be subject to a noise detection action 906. Such an action can compare sensed capacitance levels to one or more limits to determine a noise level. Following a noise detection action 906, a listening operation 900-A can repeat, performing another listening scanning action 902.

FIG. 9B shows a listening operation 900-B having pipelined noise listening operations. Progression of time is shown by arrow "t". A listening operation 900-B can begin with a listening scanning action 902-1, which can acquire a first set of raw capacitance values. Following listening scanning operation 902-1, a next listening scanning operation 902-2 can begin. However, while such second scanning action (902-2) is undertaken, the first set of raw data acquired with the first scanning action 902-1 can be common mode filtered 904-0 and subject to noise detection 906-0.

In this way, while raw data is gathered for noise listening on electrodes, previously gathered raw data can be common mode filtered and checked for noise events.

In some mutual capacitance embodiments, that drive TX electrodes with a transmit (i.e., excitation) signal while RX electrodes provide sense signals via a mutual capacitance, in a listening scanning action (e.g., 902 and/or 902-1), capacitance can be sensed on RX electrodes, but without the TX electrodes being driven with a transmit signal.

FIG. 10 shows a noise listening operation 1000 according to one embodiment in a flow diagram. An operation 1000 can include a scanning initialization 1010. A scanning initialization can configure connections to a sense network to enable the sensing of noise across multiple channels. Such an initialization can include changing sense network configurations from a standard touch sensing configuration to a noise listening configuration.

Once scanning initialization 1010 is complete, an operation 1000 can, in parallel, perform noise scanning 1012 and noise detection 1014. Noise scanning 1012 can include acquiring sense values from electrodes. Noise detection 1014 can include detecting noise from previously acquired sense values. Once noise scanning is complete (Yes from 1016), a noise listening operation 1000 can restore a sense network to a normal state 1018. A normal state can be that utilized for standard sensing operations (e.g., touch sensing).

FIG. 11 shows a scanning initialization operation 1100 according to an embodiment. A scanning initialization operation 1100 can be one particular implementation of that shown as 1010 in FIG. 10. Scanning initialization operation 1100 can be a scanning initialization operation for a mutual capacitance sense network. An operation 1100 can include disabling any circuits utilized in standard scanning operations that could interfere with noise detection (1120). In the embodiment shown, an action 1120 can include turning off current digital-to-analog converters (iDACs) connected to a sense network. RX paths can be configured as high impedance inputs (1122). RX paths can then be connected to input channels (1124). A signal acquisition time (e.g., scan time) can then be set that is suitable for the noise to be detected. In the embodiment of FIG. 11, such an action can include setting a number of sub-conversions (1126) to a predetermined value. All active channels can then be turned on (1128). Such an action can enable electrodes to be connected to capacitance sensing circuits. A scan can then start (1130). Such an action can acquire raw sense values to enable noise to be detected. A scanning initialization operation 1100 can then end.

FIG. 12 shows a restore-to-normal operation 1232 according to an embodiment. A restore-to-normal operation 1232 can be one particular implementation of that shown as 1018 in FIG. 10. Restore-to-normal operation 1232 can include disconnecting all RX paths from input channels (1234). Such RX channels can then be configured for standard sensing operations (1236). A signal acquisition time (e.g., scan time) can then be returned to that utilized for standard sensing operations (1238). In the embodiment of FIG. 12, such an action can include setting a number of sub-conversions. An operation 1232 can include enabling previously disabled circuits utilized in standard scanning operations (1240). In the embodiment shown, an action 1240 can include turning on iDACs. A restore to normal operation 1232 can then end.

FIG. 13 shows a noise detection operation 1314 according to an embodiment. A noise detection operation 1314 can be one particular implementation of that shown as 1014 in FIG. 10. A noise detection operation 1314 can include a CMF operation 1340. Such filtering can remove noise common to electrodes and thus can improve a signal from any local noise (i.e., external noise). Operation 1314 can then determine a noise value. In the particular embodiment shown determining a noise value can include finding maximum and minimum values from the CMF filtered values (1342), and then determining the difference between such values (1344).

A noise value can then be compared to a first threshold (1346). If a noise value is above a first threshold (Yes from 1346), a listening timeout value can be reset (1348) and a noise level can be set to a first value (ON) (1350). If noise has been determined to above a first threshold, the noise can also be compared to a second threshold (1352). If a noise value is above a second threshold (Yes from 1352), a noise level can be set to a second value (Alarm) (1354). An operation can then end 1366. If a noise value is below a second threshold (No from 1352), an operation can also end 1366.

If a noise value is not above a first threshold (No from 1346), a noise detection operation 1314 can determine if a noise level should be returned to a zero value (i.e., no noise). In the embodiment shown, if a noise level can be checked to see if it still indicates a high noise state (i.e., ON or Alarm) (1356). If no elevated noise is indicated (No from 1356) a timeout value can be reset (1348). If elevated noise is indicated (Yes from 1356) a timeout value can be incremented (1360). The timeout value can then be compared to a limit (1362). If a timeout value exceeds a limit (Yes from 1362), the noise level can be returned to the no noise state (1350). If a timeout value does not exceed a limit (No from 1362), an operation can end 1366.

FIG. 14 is a timing diagram showing a noise detection operation according to one embodiment. FIG. 14 includes a waveform NOISE DATA, showing noise sense values

acquired by a noise listening operation. Projected onto the NOISE DATA waveform are two noise threshold levels (1^{st}_Threshold and 2^{nd}_Threshold).

FIG. **14** also includes a waveform NOISE LEVEL that shows noise levels determined by a noise detection operation. NOISE LEVEL can indicate three different noise levels. NoiseState=OFF can show noise values below a first threshold (1^{st}_Threshold). NoiseState=ON can show noise values above the first threshold (1^{st}_Threshold). NoiseState=Alarm can show noise values above a second threshold (2nd_Threshold).

Referring still to FIG. **14**, at about time t**0**, noise values can exceed a first threshold. As a result, a noise detection operation can set a noise level to ON. Eventually, noise levels time out, and at time t**1**, noise levels can return to an OFF state.

At about time t**2**, noise values can exceed a second threshold. As a result, a noise detection operation can set a noise level to Alarm. Eventually, noise levels time out, and at time t**3**, noise levels can return to an OFF state.

Referring now to FIG. **15**, a local noise filtering operation **1516** according to an embodiment is shown in a flow diagram. A local noise filtering operation **1516** can be performed on sense data in the event local (i.e., not common mode) noise levels are determined to exceed a certain level. An operation **1516** can include inputting sense signals (**1568**). Such an action can include inputting raw count values generated from an ADC connected to sense electrodes.

An operation **1516** can find a main signal (**1570**). Such an action can locate a potential touch location. As will be recalled, local noise can present around touch locations. In one embodiment, a main signal can correspond to a sensor having a highest response (which would, in the absence of noise, indicate a touch). An operation **1516** can then scale signals from neighboring sensors to the corresponding main sensor signal (**1572**). Neighbor sensors can be sensors physically proximate to the main sensor. In one embodiment, neighbor sensors can be sensor on opposing sides of a main sensor. A scaling operation can alter a sense value of a neighbor electrode based on how such an electrode varies from the main when a valid touch event occurs.

In one very particular embodiment, scaling can be based on a mean value when a touch is present for an electrode. Sense values for neighboring electrodes can be scaled according to scaling factors as follows:

$$k_A=(B_{Tmean}/A_{Tmean}),\ k_C=(B_{Tmean}/C_{Tmean})$$

where k_A is a scaling factor for a count value from an electrode A which is a neighbor of an electrode B, k_C is a scaling factor for a count value from an electrode C which is a neighbor of an electrode B opposite electrode A, and A_{Tmean}, B_{Tmean}, and C_{Tmean} are mean sense values derived from touches to such electrodes.

Following a scaling of neighbor sensors, a median filter can be applied with respect to the main signal (**1574**). Such an action can include applying a median filter to sense values for electrodes. In one embodiment, a median filter can be applied to sensor signals from three consecutive time periods. A true touch event can provide an increase count value that may be sustained over multiple time periods. In contrast, local noise levels may vary in polarity over time. A median filter operation (e.g., **1574**) can be a first type of non-linear filtering that is performed.

An operation **1516** can also include an adaptive jitter filter (AJF) operation (**1576**). An AJF operation (e.g., **1576**) can be another non-linear filter operation. One particular example of an AJF operation is described below in more detail.

Following an AJF operation (**1576**), a previous scaling operation (e.g., **1572**) can be reversed. That is filtered sense values corresponding to neighbor sensors proximate a main sensor can be "unscaled" (**1578**). A resulting set of sense values can then be output **1580**.

FIGS. **16**A and **16**B show a determination of a main signal from electrodes according to an embodiment. FIGS. **16**A and **16**B show electrodes physically arranged into two groups, shown as slots **1684-0**/**1**. A sense operation can sense capacitance values for different slots with different sense operations. In one very particular embodiment, slots **1684-0**/**1** can be RX electrodes coupled to a same TX electrode(s) by a mutual capacitance.

FIG. **16**A shows a sense operation that determines electrode **1688** has a highest response (count in this embodiment). Consequently, such an electrode can be considered a "main" electrode. Electrodes **1686** adjacent to main electrode **1688** can be considered neighbor electrodes. Sense values corresponding to neighbor electrodes **1686** can be scaled with respect to a sense value for main electrode.

FIG. **16**B shows a sense operation in which main electrodes **1688** occur on ends of adjacent slots **1684-0**/**1**. In such an arrangement, a neighbor electrode **1686** for each main electrode can be an electrode in a different slot.

Referring now to FIGS. **17**A and **17**B, an AJF operation **1700** according to one embodiment is shown in flow diagram. An AJF can be one particular implementation of that shown as **1576** in FIG. **15**. An AJF operation **1700** can perform filtering on a subset of electrodes based on average difference of such electrodes over time. FIGS. **17**A and **17**B are different portions of a flow diagram, with connections between the two shown as circled letters "a" and "b".

Referring first to FIG. **17**A, an AJF operation **1700** can include inputting arrays of current signal values, and previously generated filtered signal values (**1702**). In the embodiment shown, this can include inputting values $Msig^{-1}\{0 \ldots k\}$ which can be previous filtered values generated by an AJF operation **1700** for an electrode set (e.g., a slot), values $Sig^{-1}\{0 \ldots k\}$ which can be previously input sense values for the same electrode set (which in some embodiments can include scaling and/or median filtering), and values $Sig\{0 \ldots k\}$ which can be current input sense values for the same electrode set.

Various values can be initialized to zero, including a positive disparity value sdp, a negative disparity value sdn, and iteration count values i and it (**1704**). As will be understood from the discussion below, a positive disparity value sdp can represent the degree of correlation in a positive change from a previous sense value set and current a sense value set. A negative disparity value sdn can represent a same correlation, but in the other (i.e., opposite polarity) direction.

An operation **1700** can determine a difference between previous sense signals and current sense signals (**1706**). In the embodiment shown, an array $Mdiff\{0 \ldots k\}$ can be created that holds such values (referred to herein as difference values).

An operation **1700** can then generate positive and negative disparity values utilizing such difference values (**1708**). In the embodiment shown, such an action can include determining if a difference between a previous sense value and its current level is positive, negative, or zero. A positive value will increase a positive disparity for the electrode set. Similarly, a negative value will decrease a negative disparity for the electrode set. In the embodiment shown, no difference in values (zero) can result in both positive and negative disparity values being increased.

Once disparity values have been generated, an operation can then calculate an average sum of the differences between sense signal sets (i.e., current and previous set) (**1710**). A function "fix" can remove a fractional part of a number (**1711**). Such an average value is shown as th_av in the embodiment of FIG. **17**. If an average difference (th_av) is above a threshold value (n from **1712**), filtering can stop, and current set of input values Sig{0 . . . k} can be saved as filter values for a next filter operation and can be output as filtered values (**1718**, **1722**, **1724**). Such a threshold check can account from a multi-touch event occurring on the set of electrodes.

If an average difference (th_av) is below a threshold value (y from **1712**), disparity values can be compared against correlation limits (**1714**). If either (i.e., positive or negative) disparity value is sufficiently small (n from **1714**) filtering can once again end, with the current set of input values Sig{0 . . . k} can be saved as filter values for a next filter operation and output as filtered values (**1718**, **1722**, **1724**).

If an average difference (th_av) is below a threshold value and correlation between sense signal sets is high (y from **1714**) an average difference value th_av can be compared against a minimum value (in this case 0) (**1716**). If there is little difference between sense signal sets (y from **1716**), a current signal sense value set and previous filtered sense value set can be averaged to create a current filtered sense value set (**1720**). This set can be saved as filter values for a next filter operation and output as filtered values (**1722**, **1724**).

Referring now to FIG. **17**B, when an average difference value (th_av) and disparity values are within predetermined ranges, an operation **1700** can call a weighting function **1726**. A weighting function can increase sense values when a limited number of sense values in a set exceed a weighing threshold. A weighting function according to one particular embodiment will be described in more detail below. A weighting function can return a weighting value (delta_av) that can be used to weight sense values in a filtered set.

If a weighting function indicates no weighting (i.e., delta_av=0) (y from **1728**), filtering can stop, and current set of input values Sig{0 . . . k} can be saved as filter values for a next filter operation and output as filtered values (**1722**, **1724**).

If a weighting function provides a weighting value (i.e., delta_av≠0) (n from **1728**), an operation can selectively weight current sense values based on polarities of a difference value and the weighting value (delta_av). In particular, if a difference value for an electrode has the different polarity as the weighting value (n from **1730**), the sense value may not be weighted.

However, if a difference value for an electrode has a same polarity than the weighting value (y from **1730**), a magnitude of difference value can be compared to the weighting value (**1732**). If a magnitude of a difference is less than that of a weighting value (n from **1732**), a multi-pass value can be checked to determine if the present operation is an initial pass (**1734**). If it is an initial weighting pass (n from **1734**), an operation **1700** can continue to a next value of the set (**1738**). However, if it is a follow on weighting pass (y from **1734**), a current value can be set to a previous filtered value, and an operation **1700** can continue to a next value of the set (**1738**). If the magnitude of a difference between sense values is greater than that of a weighting value (y from **1732**), the weighting value can be subtracted from the current value (**1740**), and an operation **1700** can continue to a next value of the set (**1738**).

When all sense values of a set have been examined for weighting, a difference set can be created from the weighted values (**1742**). A multi-pass value can then be checked to determine if the present operation is a last pass (**1744**). If the operation is not a last pass (y from **1744**), a weighting function can be called again with the updated values. If the operation is a last pass (n from **1744**), a current set of filtered values can be saved as filter values for a next operation and output as filtered values (**1722**, **1724**).

Referring now to FIGS. **18**A and **18**B, a weighting function **1800** according to one embodiment is shown in flow diagram. A weighting function **1800** can be one particular implementation of that shown as **1726** in FIG. **17**. A weighting function **1800** can weight sense values in a set of electrodes when limited numbers of electrodes in the set exceed a weight threshold. FIGS. **18**A and **18**B are different portions of a flow diagram, with a connection between the two shown as circled letter "a".

Referring first to FIG. **18**A, a weighting function **1800** can include inputting current filtered values Msig{0 . . . k} and difference values Mdiff{0 . . . k} (**1846**). A function **1800** can then examine a filtered value for each electrode in a set to see if it exceeds a weighting threshold (WTH). Each time a sense value exceeds a weighting threshold (WTH) a range value can be incremented (**1848**). Thus, a range value (range) can represent how many electrodes in a set exceed WTH.

Once a range value is established, a weighting value can be initialized (**1849**).

Each filtered value can be compared to a weighting threshold (**1850**). According to such a comparison, components of a resulting weighting value (delta_av) can be increased or decreased depending upon a range value. In the embodiment shown, if a range value outside of some minimum and maximum value (in the embodiment shown, less than or greater than two), a weighting component can be a difference value for the filtered value (delta_av=delta_av+Mdiff[i]). However, if a range value is within a predetermined range (in this embodiment, is "2"), a weighting component can be increased by multiplying by the difference value by a weighting factor (Nwg) (delta_av=delta_av+Nwg*Mdiff[i]).

Once all filtered values have been compared and components for the weighting value added up, an average of the values can be generated **1852**. In the embodiment shown, fractional portions of weighting values can then be removed (**1853**).

Referring now to FIG. **18**B, if a weighting value is zero (y from **1854**) a weighting function can end, and the weighting value (zero) can be provided as an output weighting value (**1865**) (for use in the AJF). If a weighting value is positive, a maximum difference value (Max) from the set of difference values can be determined (**1856**). If a weighting value (delta_av) is greater than a maximum value (Max), the weighting value can be set to the maximum value (**1858**). In a similar fashion, if a weighting value is negative, a minimum value (Min) from the set of difference values can be determined (**1860**). If a weighting value (delta_av) is greater than a minimum value (Min), the weighting value can be set to the minimum value (**1862**).

A weighting value (delta_av) can then be bounded by a high limit value DF_MAX and low limit value DF_MIN (**1864**). If a weighting value (delta_av) is greater than high limit, it can be set to the high limit. Similarly, if a weighting value (delta_av) is less than low limit, it can be set to the low limit.

The resulting weighting value can then be provided as an output weighting value (**1865**) (for use in the AJF).

It is understood that FIGS. **17**A to **18**B show an AJF and weighting function according to a very particular embodi-

ment. Alternate embodiments can realize such operations, or equivalent operation, with other circuits and/or architectures.

FIG. **19** is a flow diagram showing another implementation of an AJF filter and weighting function like that shown in FIGS. **17**A to **18**B. FIG. **19** shows processing **1900** that includes a first section **1966** that can generate an average difference value (th_av), a positive disparity value (sdp), and negative disparity value (sdn), as described for FIG. **17**A. A second section **1970** can generate a weighting value (delta_av) like that described for FIGS. **18**A/B. A third section **1972** can generate filter output values as shown in FIG. **17**B.

Referring now to FIG. **20**, a median filter **2000** that can be included in the embodiments is shown in a flow diagram. A median filter **2000** can include inputting a set of sense values from consecutive sample periods (i.e., a sample window) (**2003**). In the particular embodiment of FIG. **20**, a sample window is three. A median of the three values can be determined, and then provided as an output value (**2005**).

Embodiments can be utilized in capacitance sense systems to reduce the adverse affects of noise local to a subset of all electrodes, such as that arising from external noise source.

Embodiments can improve capacitance sensing of a device when it is coupled to a charging device by filtering charger noise coupled to a touch object (e.g., finger).

The frequency hopping algorithm described above can be improved upon, possibly improving stability and performance even for noise below 3 Vp-p within a range of 1-200 kHz square wave noise. The embodiments described herein may be used to meet device requirements for charger noise. One of the improvements may include modifying a state machine to implement an additional listening method independently checks actual raw counts values on each sensor to decide if a frequency change is needed. Other methods in the embodiments described below may also be used to improve baseline updates for all available configurations to maintain the baselines up to date with possible changes in the device's environment.

Generally, the embodiments described above perform noise listener scanning before normal scanning as illustrated in FIG. **1** and FIG. **2**. In order to eliminate the listener's sensitivity to LCD common node noise, a common node filter is applied to the listener data. After filtering, the noise detector defines the noise level (based on thresholds and timeout technique). If charger noise is not detected then the scanning and processing path is not charged, as illustrated in the standard scan **104**, **204**. The normal scanning (e.g. with 8 sub-conversions) with pipeline filtering, CMF, baseline and difference calculation are typically performed, as shown in **212** and **228** of FIG. **2**. If the acceptable charger noise is detected (e.g., Rx channel is not saturated and the system SNR is decreased but it is greater than 1-2) then the normal scanning time is increased (e.g., twice as many conversions or the like), as shown in the extended scan **114**, **206**. The pipeline filtering (with CMF excluded), may perform median filtering **216-0**, non-linear noise filtering **216-1**, as well as baseline and difference calculation **228**, as illustrated in FIG. **2**. If a non-acceptable noise is detected (e.g., Rx channel is saturated and the system SNR is less than 1), then a charger noise alarm flag is defined by the noise alarm **218** and the system tries to solve the problem by charger noise scanning and processing path.

The idea of frequency hopping is to detect the noise which exceeds some threshold and switch to different frequency which has the noise below threshold. If there's no one frequency in a list which meets noise requirements than it will pick the most quiet one and operate on it. The system may listen to the noise and turn on filtering in case of exceeding some other acceptable noise threshold. The combination of noise listening and filtering with frequency hopping can use three different thresholds: 1) a first noise threshold where the noise may be filtered with filters; 2) a second noise threshold where the noise cannot definitively be filtered by standard filters and may benefit from a frequency change; and 3) a third noise threshold where the noise is considered excessive noise and where the flag is sent to the host that the noise cannot be filtered.

FIG. **23** is a graph **2300** of detected noise **2301** and three noise thresholds **2302-2306** according to one embodiment. The detected noise **2301** is shown as data values (also referred to as counts) in packets being sent to the host. As shown in the FIG. **23**, the detected noise **2301** exceeds a first noise threshold **2302** at which charger armor feature is activated. The charger armor feature refers to the different combination of techniques described herein that identify, define, and filter the detected noise on the device. The phrase "charger armor feature" is used as a matter of convenience, but could include any one of the different combination of listening, detecting, and filtering techniques described herein. The detected noise **2301** may also exceed a second noise threshold **2304** at which charger armor filtering is activated and a frequency change is needed. The combination of frequency hopping with the charger armor filtering may result in better noise suppression. The detected noise **2301** may also exceed a third noise threshold **2306** at which the detected noise **2301** is considered excessive noise. The host can ignore the data (e.g., detected touches) during this condition.

FIG. **24** is a flow chart illustrating a method **2400** of noise suppression according to one embodiment. The method **2400** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **330**, **430**, **530** and **630** of FIGS. **3**, **4**, **5** and **6** performs some of operations of method **2400**. Alternatively, other components of the capacitance sensing system **300**, **400**, **500**, and **678** of FIGS. **3**, **4**, **5**, and **6** can perform some or all of the operations of method **2400**.

Referring to FIG. **24**, the method **2400** begins with calibrating all available frequencies (block **2401**), and initializing baselines for those frequencies (block **2402**). Next, the processing logic scans the panel (block **2403**) at a specified operating frequency. Next, processing logic determines if the charger armor feature of the device is enabled (block **2404**). If not, the processing logic proceeds to calculate a centroid (block **2460**) as described below. However, if at block **2404** the charger armor feature is enabled, the processing logic listens to the noise (block **2405**). The detected noise can be categorized into four levels: 1) "No Noise"—no noise is detected (e.g., noise is below the first noise threshold **2302**); 2) "Noise Level 1"—charger armor filter needed (noise is above the first noise threshold **2302**); 3) "Noise Level 3"—frequency change is needed (noise is above the second noise threshold **2304**); and 4) "Noise Level 2"—excessive noise detected (noise is above the third noise threshold **2306**).

If the processing logic determines that the noise is in the "No Noise" level, in which the noise is less than the first noise threshold (block **2410**), the processing logic disables a median filter (block **2411**). If the processing logic determines that the noise is in the "Noise Level 1" (block **2420**), the processing logic enables the median filter (block **2421**), and may perform a baseline update on the hopping frequencies (block **2422**). If the processing logic determines that the noise is in the "Noise Level 3" (block **2430**), the processing logic

enables the median filter (block **2431**), and determines whether all frequencies have been listened to (block **2432**). If not all the frequencies have been listened to at block **2432**, the processing logic selects a next available configuration (block **2433**). When all the frequencies have been listed to at block **2432**, the processing logic selects the configuration with the lowest noise (block **2434**). If the processing logic determines that the noise is in the "Noise Level 2" (block **2440**), the processing logic sets the flag "Excessive Noise" (block **2441**).

Next, the processing logic determines if the median filter is enabled (block **2450**). If not, the processing logic sets the original number of sub-conversions (block **2452**), as described above in the normal scanning. However, if the median filter is enabled, the processing logic increases the number of sub-conversions (block **2451**). For example, the number of sub-conversions can be doubled as described above in the extended scanning.

Next, the processing logic calculates a centroid (block **2560**) of the data that may or may not have been filtered. In yet a further embodiment, as depicted, the processing logic can determine if the detected noise is excessive in "Noise Level 2" (block **2440**), or the frequency change is needed in "Noise Level 3" (block **2430**) (block **2461**). If not, the processing logic returns to scan the panel at block **2403**. If yes, the processing logic assigns the previous number of touches to a current number of touches (block **2462**). This may operate as a debounce feature that may prevent reaction to glitches in the noise due to a single sample having excess noise. Also, the debounce feature may be used to track the number of touches when transitioning to a new frequency.

FIG. **25** is a flow chart illustrating a method of noise suppression with frequency hopping according to one embodiment. The method **2500** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **330**, **430**, **530** and **630** of FIGS. **3**, **4**, **5** and **6** performs some of operations of method **2500**. Alternatively, other components of the capacitance sensing system **300**, **400**, **500**, and **678** of FIGS. **3**, **4**, **5**, and **6** can perform some or all of the operations of method **2500**.

Referring to FIG. **25**, the method **2500** begins with initializing hardware (block **2501**) and initializing firmware (block **2502**). Initializing the hardware may include setting up the circuitry used to scan the electrodes of the sense network, such as the switching circuits, ADC, signal generators, etc. As part of initializing the firmware, the processing logic can assign global variables, initialize scanning settings (block **2503**) and initialize frequency hopping settings (block **2504**). Initializing the scanning settings at block **2503** may include, for example, setting the number of scanning cycles (e.g., number of sub-conversions) to be performed, which electrodes are to be scanned, a scan order, initialize any variables and thresholds associated with scanning, or the like. Initializing the frequency hopping settings at block **2504** may include, for example, setting the available number of frequencies, variables and thresholds associated with the frequency hopping algorithm, or the like. Next, the processing logic performs a pre-scan routing (block **2505**) in which the processing logic sets the scanning settings (block **2506**), and executes the frequency hopping algorithm (block **2507**). Also, as part of the pre-scanning routine, the processing logic can scan the electrodes to obtain baselines levels for the electrodes. The baselines are measured when there is no touch on the device and are used to determine a change from the baseline (raw data) is above a touch threshold. The pre-scan routing may include other systems operations as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

Next, the processing logic determines if the scanning is enabled (block **2508**). If not, the processing logic enables the scanning (block **2515**), updates the registers (block **2516**), and reports data to a host (block **2517**), returning to the pre-scan routine at block **2505**. When the scanning is enabled at block **2508**, the processing logic scans the sensors (block **2509**) and processes the results (block **2510**). As part of processing the results, the processing logic can determine a difference between the raw counts and the baseline. The raw counts may be a digital value that represents the capacitance measured on the electrodes. Also, as part of processing the results, the processing logic calculates the centroid (block **2511**). The centroid may determine a coordinate location of the touch, such as the X/Y coordinates of the touch. This may be reported in terms of pixels, or in terms of a coordinate system mapping of the touch surface. The processing logic may also perform filtering when certain conditions apply, as described herein.

In one embodiment, as part of processing the results, the processing logic may also determine if the number of fingers proximate to the sense network is greater than zero (block **2512**). If so, the processing logic updates the inactive baselines (block **2513**) and returns to active configuration (block **2514**), such as returning to block **2515**. The inactive baseline updates may update the baseline values so that they are adjusted for current conditions, such as the noise environment in which the device is currently operating. In one embodiment, a counter may be used for baseline updates. When the counter expires the updates can be designated as inactive and need to be updated when there are no touches. The counter value may be a programmable value based on the design specifications.

At block **2515**, the processing logic can have an XY position (centroid) or a flag for excessive noise, and can determine if the scanning is enabled (block **2514**), can update the registers (block **2516**), and report the data to the host (block **2517**). In one embodiment, the processing logic sends an interrupt to the host to let a driver of the operating system of the host know that there is new data. In the interim, the processing logic can return to the pre-scanning routine at block **2505** to perform another scan. In short, the method can check for noise, scan, calculate a position, and report to the host over and over while the method is operating.

It should be noted that in one embodiment, the method **2500** is performed without blocks **2504**, **2507**, **2512**, **2513**, and **2514**, as described above. In another embodiment, the method **2500** is performed with blocks **2504** and **2507**, but without blocks **2512-2514**. In another embodiment, the method **2500** is performed with blocks **2512-2514** and without blocks **2504** and **2507**.

The flow chart of FIG. **25** shows how the frequency hopping algorithm can be implemented in the architecture of a capacitive touch screen controller. In one embodiment, the capacitive touch screen controller is the TrueTouch® capacitive touchscreen controllers, such as the CY8CTMA3xx family of TrueTouch® Multi-Touch All-Points touchscreen controllers, developed by Cypress Semiconductor Corporation of San Jose, Calif. The TrueTouch® capacitive touchscreen controllers sensing technology to resolve touch locations of multiple fingers and a stylus on the touchscreens up to 5 inches, supports leading operating systems, and is optimized for low-power multi-touch gesture and all-point touchscreen functionality. Alternatively, the frequency hopping features may

be implanted in other touchscreen controllers, or other touch controllers of touch sensing devices. In one embodiment, the frequency hopping features may be implanted with the charger armor features for better noise suppression, such as from chargers.

In one embodiment, the processing logic can force a frequency hop trigger on an excessive noise activation as specified by one of the noise thresholds—frequency change activation threshold. Sometimes the noise listener cannot detect the exact condition when the false touch is going to happen and a frequency change is needed. This may be caused by the noise listener's implement in some device. For example, the noise listener's output may oscillate near the frequency change activation threshold. Even though the output may not reach the frequency change activation threshold, there may be sufficient noise to trigger a false touch. In one embodiment, the frequency change activation threshold may be lowered. However, lowering the frequency change threshold of noise listener may cause the state machine to become unstable by switching to a different frequency without finding a frequency at which the noise is quieter. In another embodiment, instead of lowering the change frequency threshold, the change frequency threshold can be set high enough to not cause continuous unstable hopping and the state machine algorithm can indicate when the frequency configuration needs to be changed, as described in more detail below. In one embodiment, this algorithm may check most or all capacitive electrodes of the sense network and count how many of the electrodes have a signal close to a finger threshold without exceeding the finger threshold. If the number of capacitive electrodes is large enough, but the listener does not reach the frequency change threshold, the algorithm can force a frequency change, such as described and illustrated in FIG. **26**.

In another embodiment, the processing logic counts a number of active electrodes among the electrodes (e.g., capacitive sense elements) of the sense network. The active electrodes are those whose respective signal is greater than a minimum touch signal value and less than a touch threshold. The processing logic initiates a frequency change to another one of the available operating frequencies when the number is greater than a threshold number. In yet a further embodiment, the processing logic determines the minimal signal value based on a signal value of one or more conductive object detected proximate to the electrodes.

FIG. **26** is a flow chart illustrates a method **2600** of forcing a frequency change according to one embodiment. The method **2600** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **330**, **430**, **530** and **630** of FIGS. **3**, **4**, **5** and **6** performs some of operations of method **2600**. Alternatively, other components of the capacitance sensing system **300**, **400**, **500**, and **678** of FIGS. **3**, **4**, **5**, and **6** can perform some or all of the operations of method **2600**.

Referring to FIG. **26**, the method **2600** begins with determining if a number of touches is greater than zero (block **2601**). If the number of touches is greater than zero, the processing logic initializes or resets a minimal signal value (minSig) (block **2602**) and sets an index to zero (block **2603**). Then for each of the touches detected (fingerNum), the processing logic determines which of the touches is the smallest. For example, a pinkie finger may produce a smaller count than a thumb. By finding the smallest touch among multiple touches, the processing logic can detect that signals above that level would be considered a touch, where signals below that level will likely be noise, such as from a charger. In the depicted embodiment, the processing logic determines the minimal signal for a touch by determining if the index is less than the number of touches detected (block **2604**), and determining if the minimum touch signal value is greater than indexed touch's signal (block **2605**). If so, the touch's signal becomes the signal (block **2606**); otherwise, the minimum touch signal value stays the same. Also, the processing logic may determine if the touch is considered to be a large touch (referred to a fat finger) (block **2607**).

A touch may be considered large using a specified number of electrodes that are activated by the touch. For example, if a touch panel included 200 sensors (200 intersections of RX electrodes and TX electrodes), a finger would cover more than a few of the sensors, such as ten or 15. A thumb may even cover 20 sensors. A programmable value may be set for the number of active sensors are needed for the touch to be considered a large touch or not. Finger size may impact the determination of noise because charging noise is noise that is localized. It is localized to the area where the touch occurs, such as on the RX lines. For example, if the touchscreen on a mobile phone is touched on the bottom of the touchscreen and the RX channels are disposed horizontally, only the bottom RX lines will have noise, and there will be less noise or no noise at the top portion of the touchscreen. In this case, if the finger is a fat finger, such as a thumb, more RX lines are covered with the touch, and more noise may be introduced.

If at block **2607** the touch is considered large, a specified fat threshold (Fat_THRSHLD) is added to a sum (block **2608**); otherwise, a regular threshold is added to the sum (block **2609**). The processing logic repeats this process for each touch, by incrementing the index (block **2610**) and determining whether the index is less than the number of touches (block **2604**).

Once the minimum touch signal value is determined from blocks **2604-2610**, the processing logic reduces the minimum touch signal value by a specified amount. In the depicted embodiment, the processing logic divides the minimum touch signal value by half (block **2611**). The processing logic sets an index to zero (block **2612**), and determines whether the index is less than the total number of intersections of the electrodes (TX/RX sensors) (block **2613**). If so, the processing logic determines how many of the sensors are active by determining if the touch signal is more than a low threshold and the signal is less than the minimum signal (block **2614**). If not, the index is incremented (block **2616**), and the processing logic returns to block **2613**. If yes at block **2614**, the processing logic increments a counter value of the number of active sensors (block **2615**), and then increments the index at block **2616**, returning to block **2613**.

Once the total number of sensors has been evaluated, the processing logic determines if the number of active sensors is greater than the sum as set in blocks **2608** and **2609**. If yes, the processing logic forces a frequency change using the frequency hopping algorithm (block **2618**) and returns the hop needed status (e.g., TRUE), and the method **2600** ends. If no at block **2617**, the processing logic returns that hop needed status (e.g., FALSE), and the method **2600** ends.

In other embodiments, the processing logic can detection a condition when the frequency change is needed even when the detected noise does not reach the change frequency threshold. For example, there may be 100 of 200 sensors that are activated, but the detected noise does not trigger the change frequency condition. The processing logic calculates how many sensor in the whole panel have this type of noise and the processing logic may previously define, based on user input for example, how low or how high the margin should be

for the signal. The margin can make it so the processing logic does not consider when the signal is above a certain threshold because it might be a touch, and it doesn't want to consider signals where one or two sensors are activated since this may be just random noise of the device. By detecting the signal within the margin, the processing logic can force a frequency change even when the noise does not rise to the level of the change frequency condition, when the noise signal is above the frequency change threshold. The margin can be determined based on the minimum signal by evaluating the signals of the number of touches detected and determining which is the smallest. This way any signal greater than the minimum signal is likely considered a touch. The minimum signal may be reduced further by another specified amount to define the one threshold. The other threshold may be set to be exclude regular noise of the system, and not localized noise like from a charger.

In the depicted embodiment, this algorithm has few configurable compile time defines such as: 1) FAT_THRSHLD—is a value to be added to wSum if finger is fat (large touch). Sometimes the value is around double finger threshold value. 2) REG_TH—is a value to be added to wSum if finger is not fat (regular touch). Usually the value is around finger threshold value. 3) LOW_TH—is a value of minimum touch signal value to be counted as active. This value should be tuned separately for each panel. This value may be estimated based on a visual assessment of the noise in the sense network.

FIGS. **27**A and **27**B are a state machine **2700** for charger armor and frequency hopping according to one embodiment. The state machine may be implemented by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **330**, **430**, **530** and **630** of FIGS. **3**, **4**, **5** and **6** performs the operations of the state machine **2700**. Alternatively, other components of the capacitance sensing system **300**, **400**, **500**, and **678** of FIGS. **3**, **4**, **5**, and **6** can perform some or all of the operations of the state machine **2700**.

Referring to FIGS. **27**A and **27**B, the processing logic determines if the charger armor is enabled **2701**. If so, the processing logic listens to the noise (block **2702**). At block **2703**, the processing logic determines if noise is detected. If noise is detected at block **2703**, the processing logic sets a quiet counter to zero (block **2709**), enables an adaptive common mode filter (ACMF) and extends the number of scans (e.g., number of sub-conversions N) (block **2710**). The processing logic determines if the detected noise at the "Noise Level 3" (block **2711**). If so, the processing logic increase a finger threshold and sets the excessive noise flag (block **2712**). If at block **2711**, the noise is not at the "Noise Level 3," the processing logic does not increase the finger threshold and does not set the excessive flag, skipping block **2712**. Next, the processing logic determines if the detected noise at the "Noise Level 2" (block **2713**). If so, the processing logic increases the finger threshold (block **2718**). If the detected noise is not at the "Noise Level 2," the processing logic determines if a hop is needed (block **2714**). If so, the processing logic increases the finger threshold at block **2718**. At block **2719**, the processing logic determines if there is another configuration available. If so, the processing logic switches to the next available configuration (block **2720**, and listens to the noise (block **2721**). The processing logic determines if the noise is at the "Noise level 2" or if the hop is needed (block **2722**). If so, the processing logic returns to the next configuration available at block **2719**. If no at block **2722**, the processing logic listens to the all the frequencies and saves each noise level for each frequency (block **2723**), and sets the active configuration with the minimal level of noise (block **2724**). Also, if at block **2719** if there is no more configurations available, the processing logic passes the operations **2720**-**2722** and listens to the all the frequencies and saves each noise level for each frequency (block **2723**), and sets the active configuration with the minimal level of noise (block **2724**). In either case, the processing logic sets the "Frequency Changed" flag (block **2725**) and the processing logic proceeds to block **2726** to perform a scan of the panel.

Returning to block **2714**, if the processing logic determines that a frequency hop is not needed, the processing logic increases the finger threshold (block **2715**), sets the "Noise Level 1" flag (block **2716**), and resets the "Next Configuration Available" flag (block **2717**), and the processing logic proceeds to block **2726** to perform a scan of the panel.

Returning to block **2703**, if the processing logic does not detect noise, the processing logic resets the "Next Configuration Available" flag (block **2704**), increments the quite counter (block **2705**), disables the ACMF filter and sets the default number of scans (e.g., number of sub-conversions N) (block **2706**). The processing logic determines if the quiet counter is greater than a specified threshold value (e.g., **200**). If so, the processing logic resets the active configuration to the default configuration (block **2708**) and the processing logic proceeds to block **2726** to perform a scan of the panel. Otherwise, if no at block **2707**, the block **2708** is skipped, and the processing logic proceeds to block **2726** to perform a scan of the panel.

Returning back to block **2701**, if the processing logic determines that the charger armor is not enabled, the processing logic proceeds to block **2726** to perform a scan of the panel.

At block **2726**, the processing logic performs the scan of the panel. Next, the processing logic processes the data (block **2727**). The processing logic determines whether the number of touches has changed (block **2728**). If so, the processing logic determines if the "Frequency Changed" flag is set (block **2729**). If so, the processing logic reports the previous data for a specified number (X) of debounce cycles for the debounce feature (block **2730**). If at block **2728** the answer is no, the processing logic skips block **2729** and **2730**. If at block **2729** the answer is no, the processing logic skips block **2730**.

Next, processing logic determines if the "Excessive Noise" flag is set (block **2731**). If so, the "Excessive Noise" flag is reported to the host (block **2733**). If not at block **2731**, the processing logic holds the previous touch data (block **2732**) and reports to the host (block **2733**). The state machine **2700** may return to the block **2701** and repeat the operations while the device is operating.

In one embodiment, a baseline update may be called as part of the centroid calculation, instead of in the pre-scanning routine. In another embodiment, the state machine may select the quiet frequency based on listening all frequencies in one cycle before making a decision on which one to use. In other embodiments, some state machine reset conditions may be added to go back to normal hopping order after detecting noise on all frequencies and trying to find the quietest one. In another embodiment, similar performance on actual filtering of input data can be achieved by removing additional features for debouncing and holding XY data on frequency change event or excessive noise. This might result in unwanted false touches but may not impact input data filtering. For example, in one embodiment, the state machine **2700** can be modified to remove blocks **2728**-**2732**. In another embodiment, the ACMF filtering can be excluded and frequency hopping may be performed. For example, in one embodiment, the state

machine **2700** can be modified to remove blocks **2710** and **2706** (or at least portions of block **2710** and **2706**). In this embodiment, the noise suppression performance may be lower, but might still be good enough for some designs. The state machine **2700** can be considered to have two parts 1) frequency hopping algorithm; and 2) Non-linear ACMF filtering. As described above, the state machine may perform one or the other as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

In one embodiment, the state machine performs a method in which the processing logic monitors a signal on multiple electrodes of a sense network at a multiple operating frequencies and determines a noise level of the signal at the multiple operating frequencies. In one embodiment, the processing logic analyzes a time domain signal to analyze the signal at the different frequencies. In another embodiment, the processing logic may perform a fast Fourier transform (FFT) to analyze the signals in the frequency domain as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. The processing logic selects one of the multiple operating frequencies based on the determine noise levels for scanning the multiple electrodes to detect a conductive object proximate to the multiple electrodes. In one embodiment, the processing logic selects one of the multiple operating frequencies with a lowest noise level. In another embodiment, the processing logic selects any one of the frequencies that are below a specified threshold level, or one of the frequencies in which the noise level is determined to be acceptable. For example, the processing logic may not select the frequency that has the lowest noise level, but may select another frequency that has the second to lowest noise level, or the like. In another embodiment, the processing logic defines a first noise level with the lowest noise level, scans the multiple electrodes in a first scan to detect the conductive object proximate to the multiple electrodes at the selected operating frequency, and filters results of the first scan for localized noise events using the first noise level.

In another embodiment of the method, the processing logic determines if noise is detected on the multiple electrodes. When the noise is detected, the processing logic determines whether the noise is above three noise thresholds. When the noise is above a first of the three noise thresholds, the processing logic activates a first high-noise condition. When the noise is above a second of the three noise thresholds, the processing logic activates a second high-noise condition. When the noise is above a third of the three noise thresholds, the processing logic activates a third high-noise condition. In one embodiment, in the first high-noise condition, the processing logic performs a first position scan of the multiple electrodes, and filters results of the first position scan of the multiple electrodes for localized noise events using a noise filter. In another embodiment, in the second high-noise condition, the processing logic initiates a frequency change to another one of the multiple operating frequencies, and performs a first position scan of the multiple electrodes at the other one of the multiple operating frequencies. In another embodiment, in the third high-noise condition, the processing logic generating an alarm condition that the noise cannot be filtered.

In another embodiment, when the noise is below the three noise thresholds, the processing logic disables a noise filter configured to filter for localized noise events when the noise is below the three noise thresholds.

In yet another embodiment, the processing logic counts a number of active electrodes among the multiple electrodes. The active electrodes are those whose respective signal is greater than a minimum touch signal value and less than a touch threshold. When the number is greater than a threshold number, the processing logic initiates a frequency change to another one of the multiple operating frequencies. In a further embodiment, the processing logic determines the minimal signal value based on a signal value of one or more conductive object detected proximate to the multiple electrodes.

In one embodiment, the state machine is implemented in a capacitance sensing system, including a memory device, and a controller coupled to the memory device. The controller may receive signals from a sense network comprising multiple electrodes to detect a conductive object proximate to the multiple electrodes. In one embodiment, the controller includes a noise listening circuit configured to detect a noise level on the multiple electrodes at a multiple operating frequencies, and a frequency hopping state machine configured to select one of the multiple operating frequencies based on the detected noise levels. In one embodiment, the frequency hopping state machine is configured to select the operating frequency with a lowest noise level. Alternatively, the frequency hopping state machine may select other acceptable operating frequencies as described herein. In a further embodiment, the controller also includes a filtering circuit configured to filter for localized noise events when activated.

In one embodiment, the controller is configured to define a first noise level with the lowest noise level and scan the multiple electrodes in a first scan to detect the conductive object proximate to the multiple electrodes at the selected one of the multiple frequencies. The filtering circuit can be used to filter results of the first scan for the localized noise events using the first noise level. In another embodiment, the controller is configured to determine if noise is detected on the multiple electrodes. When the noise is detected, determine whether the noise is above three noise thresholds, the controller can 1) activate a first high-noise condition when the noise is above a first of the three noise thresholds, 2) activate a second high-noise condition when the noise is above a second of the three noise thresholds, 3) activate a third high-noise condition when the noise is above a third of the three noise thresholds, 4) and disable the filtering circuit when the noise is below the three noise thresholds. In yet a further embodiment, the controller includes an alarm circuit to generate an alarm condition when the noise is above the third noise threshold level.

In another embodiment, the sense network includes multiple electrodes, including a first set of transmit (TX) electrodes and a second set of receive (RX) electrodes. In this embodiment, the controller is configured to measure a mutual capacitance between at least one of the first set of TX electrodes and an individual one of the second set of RX electrodes. In one embodiment, the noise listening circuit is configured to detect the noise level on the second set of RX electrodes. In another embodiment, the noise listening circuit is configured to detect the noise level on the first set of TX electrodes and the second set of RX electrodes.

In another embodiment, a host device includes a display, a capacitance sensing array disposed in connection with the display, and a touchscreen controller coupled to the capacitance sensing array. The capacitance sensing array may include multiple electrodes, such as in rows and columns of electrodes. The intersections between the column and row electrodes may be considered sensors for measuring mutual capacitance, such as those of an all-points-addressable (APA) array. The capacitance sensing array may also be disposed in self-capacitance configurations. The capacitance sense array may be similar to the sense network as described herein. The touchscreen controller includes a capacitance sensing circuit coupled to the capacitance sensing array, and a noise listening

circuit coupled to the capacitance sensing array. The noise listening circuit is configured to detect noise on the capacitance sensing circuit from at least one noise source at multiple frequencies. The touchscreen controller is configured to select one of the multiple frequencies, such as the frequency with a lowest noise level, for subsequent scanning of the capacitance sensing array. In another embodiment, the touchscreen controller is configured to apply a noise filter to an output of the capacitance sensing circuit when noise is above a first noise threshold and below a second noise threshold. The noise filter may be at least one of a common mode filter, a local noise filter, a median filter, a non-linear filter, or an adaptive jitter filter (AJF).

The state machine may be modified in various ways as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. For example, modifications may be made in the frequency hopping state machine to improve system stability and efficiency. In one embodiment, the baseline update can be called in the centroid calculation instead of in the pre-scanning routine. In another embodiment, modifications can be made to incorporate an inactive baseline update, as illustrated in FIG. **28**.

FIG. **28** is a flow chart illustrate a method **2800** of an inactive baseline update according to one embodiment. The method **2800** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **330**, **430**, **530** and **630** of FIGS. **3**, **4**, **5** and **6** performs some of operations of method **2800**. Alternatively, other components of the capacitance sensing system **300**, **400**, **500**, and **678** of FIGS. **3**, **4**, **5**, and **6** can perform some or all of the operations of method **2800**.

Referring to FIG. **28**, the method **2800** begins with determining if there are touches detected (block **2801**), for example, by determining if the number of touches (fingerNum) is equal to zero. If yes, the processing logic determines if a counter, baseline update counter, is greater than a specified threshold, update_needed (block **2802**). If yes at block **2802**, the processing logic determines if the baseline update number is not equal to the active configuration (block **2804**). If yes at block **2804**, the processing logic switches the baseline update number configuration (block **2805**) and listens to the noise (block **2806**). Next, the processing logic determines if the noise is detected (block **2807**). If the noise is not detected, the processing logic disables ACMF filter (block **2808**), scans the sensors (block **2809**), updates baselines (block **2810**), restores the ACMF filter settings (block **2811**), switch back to the active configuration (block **2812**), resets the baseline update counter (block **2813**), and increments the baseline update number. Returning back to block **2804**, if the processing logic determines that the baseline update number is not the active configuration, the processing logic skips blocks **2805-2813**, and the processing logic proceeds to block **2814** to increment the baseline update number.

Next, the processing logic determines if the baseline update number if greater than the available configurations (block **2815**). If yes at block **2815**, the processing logic resets the baseline update number to zero (block **2816**), and ends the baseline update (block **2817**). Returning back to block **2807**, if the processing logic does not detect noise, the processing logic ends the baseline update at block **2817**. Returning back to block **2802**, if the processing logic determines that the baseline update counter is not greater than the specified threshold, the processing logic increments the baseline update counter (block **2803**), and proceeds to block **2817** to end the baseline update.

In one embodiment, the baseline update algorithm may be performed for inactive frequencies for each user defined number of UPDATE_NEEDED cycles for one frequency even if the noise level for active configuration is high. In another embodiment, an additional check for noise level for this particular configuration that needs an update may be performed before updating the baselines. The baselines may bee updated in cases of no touch on the panel and a quiet noise state. These embodiments may improve the baseline correction and baseline tracking under different environmental conditions, such as those caused by temperature, humidity, or the like.

The embodiments described herein provide an improvements to existing listening methods to force frequency hops that helps the state machine be more stable, eliminating unnecessary hopping as described above. The embodiments described herein also describe a debounce algorithm that may prevent reporting touches on a first cycle after the frequency configuration is changed. This may be done to make sure that the new configuration is quite enough. The embodiments described herein may listen to all the frequencies and select the quietest one. The algorithms may listen to all available configurations in the same scanning cycle prior to selecting one. This may reduce the use of prior history of the frequencies when the noise environment may have been different than the current noise environment. The embodiments described herein may also prevent reporting of position changes in excessive noise conditions to prevent sending false, unexpected touches to the host.

The embodiments described herein may be used by a capacitance sensing system that uses a touchscreen controller to perform panel scanning of the sense network, such as an ITO panel. Scanning the frequency at which the panel is being scanned may interact with the external noise source and may cause unwanted noise in the capacitance sensing system. The embodiments described herein can be used to detect the noisy conditions and switches to frequencies to avoid overlapping with the frequencies of the external noise sources. This may be done by switching the operating frequency between the available operating frequencies using the frequency hopping algorithm described herein.

The embodiments described herein may be used in devices with requirements of 3Vpp noise with 30% duty cycle and a frequency range of 1-200 kHz. Alternatively, the embodiments may be used in other devices that have different requirements as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure.

It should be noted that various embodiments are described in the context of capacitance sensing techniques on touch devices. Other types than capacitance sensing device are affected by external noise sources, but some of these devices use signals on some frequencies that are not dependent on other external devices. For example, a radio should work on the same frequency as the other external devices. However, if the device is using the signal on some particular frequency, such as for its internal use, the embodiments described herein can be used in such devices. Modifications to the listening and frequency hopping techniques may need to be modified based on the particulars of the device in which they are used. however, these modifications would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. The embodiments described herein can be used to find a quite frequency in the operational frequencies of the device. The quite frequency may not overlap with any external noise source so as to result in noise suppression in the system. The

embodiments described herein may listen to all available frequencies every time to pick the quietest one after all configurations were tried. The embodiments described herein may also perform a filter reset when transitioning to a new frequency to avoid false touches or lift-offs. The embodiments described herein may also perform an additional force hop activation algorithm for avoiding false touches even when the noise does not rise to the level of exceeding the change frequency threshold. The frequency hopping algorithm may be configured to hop between multiple frequencies, such as 2 or more available operating frequencies as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. The embodiments described herein may increase a finger threshold when the detected noise is above a specified threshold as described above.

The embodiments described below include 'frequency selection' with two frequency sets, referred to herein as 'frequency set selection'. In these embodiments, two frequency sets include two or more operating frequencies. The frequency sets may be separated at a significant distance. For example, in one embodiment, the difference of frequencies between the first and second frequency sets is greater than 80 kHz. This separation in frequencies may be measured from the upper set's maximum frequency and the lower set's minimal frequency should be more than 80 kHz. FIG. **29** shows an example of frequency sets' positions.

FIG. **29** is a graph **2900** illustrating two frequency sets **2910**, **2920** of operating frequencies on a TX signal frequency axis according to one embodiment. The lower frequency set **2910** includes three operating frequencies, including F_L**0 2912**, F_L**1 2914**, and F_L**2 2916**. The upper frequency set **2920** includes three operating frequencies, including F_U**0 2922**, F_U**1 2924**, and F_U**2 2926**. In one embodiment, the F_L**0 2912** is 103 kHz, F_L**1 2914** is 117 kHz, F_L**2 2916** is 127 kHz, F_U**0 2922** is 163 kHz, F_U**1 2924** is 180 kHz, and F_U**2 2926** is 194 kHz. In this embodiment, a separation **2932** in frequencies within the lower set **2910** is less than 30 kHz and a separation **2933** in frequencies within the upper set **2920** is close to 30-31 kHz. A separation **2931** in frequencies between the lower set **2910** and the upper set **2920** is equal to or greater than 80 kHz. In this embodiment, the lower set **2910** and the upper set **2920** both include three operating frequencies per set. In another embodiment, one of the lower set **2910** or upper set **2920** include only two operating frequencies, while the other includes three or more. In another embodiment, the lower set **2910** and the upper set **2920** includes three or more operating frequencies each.

Frequency selection and frequency set selection can be implemented by computing multiple noise metrics. For example, one solution to switch frequencies is based on two metrics groups, each having one or more noise metrics. The first metrics group is responsible for switching the frequencies inside one set and the second metrics group is responsible for switching between the frequencies sets. The values of the metrics for the upper and lower sets differ because the scanning successions in them differ. FIG. **30** illustrates sub-conversions of multiple conversions that can be used for the noise metrics calculation. It should be noted that sub-conversions may be one or any number of samples of the capacitance values measured on the plurality of electrodes. As described herein, the sub-conversions are sample values representing the capacitance values measured on the electrodes and the conversions are a specified number of sub-conversions.

FIG. **30** is a graph **3000** illustrating sub-conversions of capacitance values measured during multiple conversions over time according to one embodiment. The graph **3000** includes sub-conversion data ($SubConvData_{1,k}$) **3002** in each of the conversions **3004** (1^{st} conversion to Nth conversion). In each of the conversions, a local absolute maximum **3012** is determined. There are three noise metric calculations described below: a first noise metric (NM**1**), a second noise metric (NM**2**), and third noise metric (NM**3**). Different combinations of these noise metrics can be used to switch between frequencies within a set and to switch between frequency sets.

In one embodiment, two noise metrics, namely NM**2** and NM**3**, are used for switching between the frequencies of one set. The main noise metric, NM**2**, uses the sub-conversion values obtained from the listening scanning and is calculated according to following formula:

$$NM2 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \cdot \left| \sum_{k=1}^{N_{sub}} SubConvData_{i,k} \right|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100$$

The NM**2** is measured between 0 and 100. A dynamic threshold may be used for noise NM**2** as necessary because this noise metrics is not sensitive to noise amplitude as described in more detail below. The dynamic threshold allows correct switching between frequencies in the one set. In another embodiment, the NM**2** can be made to be dependent on noise amplitude by using a coefficient with the NM**2** calculation that is dependent on the noise amplitude. But, it may be simpler to create a dynamic threshold as shown in FIG. **31**, which shows experimental dependencies of the NM**2** from the NM**1**. In one embodiment, cubic fitting shows good approximation of the dependence, but it is not possible to realize in integer mathematics. Therefore, a piecewise linear function may be used for implementing the dynamic threshold for NM**2** in firmware or other processing logic.

FIG. **31** is a graph **3100** illustrating a non-linear dependence of NM**2** and NM**1** and a cubic fit **3106** of the same according to one embodiment. The non-linear dependence of NM**1 3102** vs. NM**2 3104** is represented by the cubic fit **3106**. The cubic fit **3106** can be expressed with the following equation:

$$y = A + B*x + C*x^2 + D*x^3$$

Although cubic fitting shows good approximation of the non-linear dependence, a piecewise linear function **3108** can be used to approximate the non-linear dependence. The piecewise linear function **3108** can be used as the dynamic threshold for NM**2 3104**.

Two metrics of the second group can be used for switching between the frequency sets. The first of the two noise metrics, NM**3**, uses the sub-conversions values obtained in the following scanning and is calculated according to following formula:

$$NM3 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \cdot \sum_{k=1}^{N_{sub}} |SubConvData_{i,k}|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100$$

The NM**3** is measured between 0 and 100. NM**3** reflects the energy of the noise component of the signal. The second noise metric for both groups metrics for both metrics groups uses the sub-conversions or sample values obtained during the listening scanning. There is an absolute value maximum **3012**

among the sub-conversions **3002** or sample values in each conversion **3004**. The average sum of the found local maximums **3012** is used as a metrics and is calculated according to following formula:

$$NM1 = \frac{1}{N}\sum_{i=1}^{N} \max_i (\{|SubConvData|\})$$

N is the number of conversions **3004** in listening scanning.

In one embodiment, the first group of noise metrics includes NM**2** and NM**1** for switching between frequencies within one set and the second group of noise metrics includes NM**2** and NM**1** for switching between frequency sets.

In one embodiment, processing logic (e.g., hardware, software, firmware or any combination thereof) is configured to monitor a signal on multiple electrodes of a sense network. The sense network is configured to operate according to multiple operating frequencies within two frequency sets, namely a first frequency set and a second frequency set. The processing logic determines a first group of one or more noise metrics of noise in the signal and determines a second group of one or more noise metrics of the noise in the signal. The processing logic switches from a first operating frequency in the first frequency set to a second operating system in the first frequency set based on the first group of noise metrics and switches from the first operating frequency to a third operating frequency in the second frequency set based on the second group of noise metrics. In one embodiment, the processing logic switches from the first operating frequency to the third operating frequency by switching to one of the frequencies in the second frequency set that is farthest away in frequency from the first operating frequency. Alternatively, the processing logic can switch to other frequencies in the second set based on other criteria.

In one embodiment, the first frequency set includes three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the first frequency set. The second frequency set (upper or lower) may include three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the second frequency set. Alternatively, the second frequency set may include two non-overlapping frequency bands, each centered at one of two operating frequencies of the second frequency set. In one embodiment, a first separation in frequencies between the first frequency set and the second frequency set is greater than a second separation in frequencies within the first frequency set and than a third separation in frequencies within the second frequency set.

In one embodiment of determining the second group of noise metrics, the processing logic obtains multiple sub-conversions that represent capacitance values measured on the electrodes. The processing logic calculates the NM**3** based on the sub-conversions, where NM**3** represents an energy level of the noise in the signal. The processing logic calculates NM**1** based on the sub-conversions, where NM**1** represents an average sum of absolute value maximums among the sub-conversions in a number of conversion. The second group includes the calculated NM**1** and NM**3**. In one embodiment of determining the first group of noise metrics, the processing logic calculates NM**2** based on the sub-conversions and uses NM**1**, which is already calculated for the second group of noise metrics.

In the embodiments described below, various switching techniques can be used to determine when to switch to a different frequency within a set and to switch to a different frequency set. For example, a first switching technique uses a state machine to frequency hop and frequency set hop as described below.

FIG. **32** is a state diagram **3200** illustrating a first frequency switching technique according to an embodiment. The state diagram **3200** includes a state for each of the operating frequencies and the states are grouped into the two sets. In particular, the first frequency set **2910**, which may be the lower set, includes a first operating frequency state **3212** (F_L**0**), a second operating frequency state **3214** (F_L**1**), and a third operating frequency state **3216** (F_L**2**). The second frequency set **2920**, which may be the upper set, includes a fourth operating frequency state **3222** (F_U**0**), a fifth operating frequency state **3224** (F_U**1**), and sixth operating frequency state **3226** (F_U**2**).

In one embodiment, the mutual changeover between frequencies (e.g., f**1**↔ f**2**) within a frequency set is a priority, keeping with the frequency selection techniques. If the state machine **3200** determines that no frequency provides the necessary noise level, the frequencies continue switching in the cycle and the number of the passed cycles may be counted by the cycle counter. Frequency set switching may be possible on two conditions: first, if the noise metrics indicate that a set hop is needed; or second, if no frequencies in current set provide acceptable noise level, such as after dynamically inspecting all operating frequencies in the set. It should be noted that frequency set switching is allowed from any operating frequency to any other operating frequency. However, in one embodiment, a hop from one set to another set may be realized using the most faraway frequencies (F_L**1** and F_U**2**). That is hop from lower set to upper set occurs to F_U**2** and inversely to F_L**1**. Alternatively, other settings may be used for frequency set hops.

Described below is a second frequency switching technique. The main purpose of this technique is to determine an operating frequency with the least amount of noise within a current frequency set. This technique performs three listening scans for finding the quietest operating frequency in the set. If no quite frequency is found, then the technique can switch frequency sets. This switching technique may provide optimal operating frequencies based on the actual noise in the operating frequencies, but may decrease the panel's refresh rate. Frequency set switching may be possible on two conditions: first, if the operating frequencies in the current set do not provide an acceptable noise level, second, even when the quietest operating frequency is found in the current set (using NM**2**), other noise metrics indicate that a set hop is needed.

Similar to the first switching technique, the frequency set switching is allowed from any operating frequency to any other operating frequency. However, in one embodiment, a hop from one set to another set may be realized using the most faraway frequencies (F_L**1** and F_U**2**). That is hop from lower set to upper set occurs to F_U**2** and inversely to F_L**1**. However, in this second switching technique no prioritized switching is used.

FIG. **33** is a flow chart illustrating a second frequency switching technique **3300** according to an embodiment. The method **3300** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **3300** performs some of operations of method **3300**. Alternatively, other components of the capacitance sensing systems can perform some or all of the operations of method **3300**.

Referring to FIG. **33**, the method **3300** begins operations for determining whether a frequency hop is needed by finding a minimum noise metric for NM**2** at a current frequency set (block **3304**) and setting the operating frequency with the minimum noise in the current set (block **3306**). Additional details of block **3304** are described and illustrated with respect to FIG. **34**. The processing logic switches the frequency set if needed (block **3308**). Additional details of block **3308** are described and illustrated with respect to FIG. **35**. The processing logic applies a raw data offset (block **3310**) and performs a listen scan (block **3312**), and the method ends. In this embodiment, if a frequency hop is needed, the processing logic performs three listen scans and stores the value of NM**2** and noise metric information about frequency set selection. As noted above, FIG. **34** and FIG. **35** show the algorithms of frequency search with minimum noise in the set (block **3304**) and sets switching (block **3308**).

FIG. **34** is a flow chart illustrating a method **3400** of determining a minimum NM**2** at a current set for the second frequency switching technique according to an embodiment. The method **3400** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **3400** performs some of operations of method **3400**. Alternatively, other components of the capacitance sensing systems can perform some or all of the operations of method **3400**.

Referring to FIG. **34**, the processing logic beings with initializing values of a counter and a register indicating a need for frequency set selection (block **3402**), and the processing logic determines if the count is less than AFH_NUM_FREQ AFH_NUM_FREQ is the number of TX frequencies in one set (lower or upper), such as 3 TX frequencies for both sets. Block **3404** is used to cycle through all TX frequencies in one set. If so, the processing logic sets the frequency (block **3406**) and performs a listening scan (block **3408**). The processing logic determines the NM**2** and sets the registers to a first value (block **3410**). The processing logic determines if a hop is needed (block **3412**). If not, the count is incremented (block **3416**) and returns to block **3404**. If a hop is needed at block **3412**, the processing logic increments the register representing the need for frequency set selection (block **3414**), then increments the count (block **3416**), and returns to block **3404**.

If the block **3404** is a no, the processing logic sets the count to one, and sets afh_txconfigindexTemp to one. The variable afh_txconfigindexTemp contains a temporary index for the current TX frequency in the set. The block **3418** initialize the algorithm to find the quietest frequency using data from a NM**2**[ ] array. The processing logic then determines if the count is less than AFH_NUM_FREQ (block **3420**). If so, the processing logic determines if NM**2** is less than the minimum NM2 (block **3422**). If not, the counter is incremented (block **3426**), and returns to block **3420**. If yes at block **3422**, the processing logic sets the NM**2** to be the minimum NM**2**, and the index afh_txconfigindexTemp is incremented (block **3424**), then increments the counter (block **3426**), and returns to block **3420**. When at block **3420**, the processing logic returns (to block **3306** in FIG. **33**).

FIG. **35** is a flow chart illustrating a method **3500** of determining if switching frequency sets is needed from the current set for the second frequency switching technique according to an embodiment. The method **3500** may be performed by processing logic that may comprise hardware (circuitry, dedicated logic, etc.), software (such as is run on a general purpose computing system or a dedicated machine), firmware (embedded software), or any combination thereof. In one embodiment, the controller **3400** performs some of operations of method **3500**. Alternatively, other components of the capacitance sensing systems can perform some or all of the operations of method **3400**.

Referring to FIG. **35**, the processing logic (block **3502**) determines if the register for the need to set hop is equal to AFH_NUM_FREQ or NMs shows that hop needed. The block **3502** checks the condition if frequency set switching is needed. This may be possible if 1) If all available three frequencies in the current set are unacceptable (NeedSetsHopping==AFH_NUM_FREQ (e.g. 3). (Block **3414**); or 2) if NMs (NM**1** & NM**3**) indicates that a set switch is needed. This condition is checking only for one TX frequency which was defined in blocks **3418**-**3426**. The processing logic switches frequency sets (block **3504**). If the condition of Prev_AFH_Set==0 and AFH_Set==1 is met at block **3506**, the processing logic switches to the highest frequency in the upper set (F_U**2**) (block **3510**). Otherwise, the processing logic switches to the lowest frequency in the lower sets (F_L**1**) (block **3512**). In one embodiment, the frequency set hop may be to the upper operating frequency in the upper set from any of the lower set operating frequencies or to the lower operating frequency in the lower set from any of the upper set operating frequencies. If not, the processing logic returns to block **3310** of FIG. **33**.

The embodiments described herein provide the possibility to switch between sets of frequencies (and frequencies in one set). The listener mode can be done by scanning with a disabled TX excitation signal. It should also be noted that various embodiments used two frequency sets with three operating frequencies per set. In other embodiments, other number of operating frequencies than six may be used, such as four, five, or more than six. Also, the number of frequencies can be decreased per set, such as two. Also, two specific switching techniques are disclosed herein, however, other switching techniques to switch between operating frequencies within a set and to switch between sets may be used as would be appreciated by one of ordinary skill in the art having the benefit of this disclosure. Also, the embodiments described above are described in the context of capacitance measurements. However, the embodiments can be used in other applications, such as other ADC-based measurements in noisy environment to improve noise immunity of the system using these embodiments.

Embodiments of the present invention, described herein, include various operations. These operations may be performed by hardware components, software, firmware, or a combination thereof. As used herein, the term "coupled to" may mean coupled directly or indirectly through one or more intervening components. Any of the signals provided over various buses described herein may be time multiplexed with other signals and provided over one or more common buses. Additionally, the interconnection between circuit components or blocks may be shown as buses or as single signal lines. Each of the buses may alternatively be one or more single signal lines and each of the single signal lines may alternatively be buses.

Certain embodiments may be implemented as a computer program product that may include instructions stored on a computer-readable medium. These instructions may be used to program a general-purpose or special-purpose processor to perform the described operations. A computer-readable medium includes any mechanism for storing or transmitting information in a form (e.g., software, processing application) readable by a machine (e.g., a computer). The computer-readable storage medium may include, but is not limited to, magnetic storage medium (e.g., floppy diskette); optical stor-

age medium (e.g., CD-ROM); magneto-optical storage medium; read-only memory (ROM); random-access memory (RAM); erasable programmable memory (e.g., EPROM and EEPROM); flash memory, or another type of medium suitable for storing electronic instructions. The computer-readable transmission medium includes, but is not limited to, electrical, optical, acoustical, or other form of propagated signal (e.g., carrier waves, infrared signals, digital signals, or the like), or another type of medium suitable for transmitting electronic instructions.

Additionally, some embodiments may be practiced in distributed computing environments where the computer-readable medium is stored on and/or executed by more than one computer system. In addition, the information transferred between computer systems may either be pulled or pushed across the transmission medium connecting the computer systems.

Although the operations of the method(s) herein are shown and described in a particular order, the order of the operations of each method may be altered so that certain operations may be performed in an inverse order or so that certain operation may be performed, at least in part, concurrently with other operations. In another embodiment, instructions or sub-operations of distinct operations may be in an intermittent and/or alternating manner.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

What is claimed is:

1. A method comprising:

monitoring a signal on a plurality of electrodes of a sense network, the sense network to operate in a first frequency set or a second frequency set, each comprising a plurality of operating frequencies;

determining a first group of one or more noise metrics of noise in the signal;

determining a second group of one or more noise metrics of the noise in the signal;

performing a frequency hop within the first frequency set based on the first group of one or more noise metrics, wherein the frequency hop switches from a first operating frequency to a second operating frequency within the first frequency set; and

performing a frequency set hop from the first frequency set to the second frequency set based on the second group of one or more noise metrics, wherein the frequency set hop switches from the first operating frequency in the first frequency set to an operating frequency in the second frequency set.

2. The method of claim **1**, wherein a first separation in frequencies between the first frequency set and the second frequency set is greater than a second separation in frequencies within the first frequency set.

3. The method of claim **1**, wherein the first frequency set comprises three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the first frequency set.

4. The method of claim **3**, wherein the second frequency set comprises three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the second frequency set.

5. The method of claim **3**, wherein the second frequency set comprises two non-overlapping frequency bands, each centered at one of two operating frequencies of the second frequency set.

6. The method of claim **1**, wherein the switching from the first frequency set to the second frequency set comprises switching from the first operating frequency to one of the plurality of operating frequencies in the second frequency set that is farthest away in frequency from the first operating frequency.

7. The method of claim **1**, wherein the determining the second group of one or more noise metrics comprises:

obtaining a plurality of sub-conversions representing capacitance values measured on the plurality of electrodes;

calculating a third noise metric (NM**3**) based on the plurality of sub-conversions, wherein the NM**3** represents an energy of the noise in the signal; and

calculating a first noise metric (NM**1**) based on the plurality of sub-conversions, wherein the NM**1** represents an average sum of absolute value maximums among the sub-conversions in a number of conversions, wherein the second group of one or more noise metrics comprises the NM**1** and the NM**3**,

wherein the determining the first group of one or more noise metrics comprises calculating a second noise metric (NM**2**) based on the plurality of sub-conversions, and

wherein the first group of one or more noise metrics comprises the NM**2** and the NM**1**.

8. The method of claim **7**, wherein the calculating the NM**1**, NM**2**, and NM**3** comprises calculating the NM**1**, NM**2**, and NM**3** based on the following equations:

$$NM2 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \cdot \left| \sum_{k=1}^{N_{sub}} SubConvData_{i,k} \right|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100,$$

where N is the number of conversions in a listening scan, $SubConvData_{i,k}$ is the plurality of sub-conversions in each of the number of conversions;

$$NM3 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \sum_{k=1}^{N_{sub}} |SubConvData_{i,k}|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100; \quad \text{and}$$

$$NM1 = \frac{1}{N} \sum_{i=1}^{N} \max_i (\{|SubConvData|\}).$$

9. The method of claim **1**, wherein the determining whether the frequency set hop is needed comprises at least one of:

determining that the plurality of operating frequencies in the first set exceed a threshold noise level after a specified number of cycles through the plurality of operating frequencies in the first frequency set; or

determining that a third noise metric (NM**3**), calculated from a plurality of sub-conversions exceeds a threshold value, wherein the NM**3** represents an energy of the noise in the signal.

10. The method of claim 7, further comprising:
identifying the plurality of operating frequencies in a current set of the first frequency set and the second frequency set with a minimum noise metric of the NM2;
switching from a current operating frequency of the plurality of operating frequencies in the current set to the operating frequency with the minimum noise metric of the NM2; and
determining whether a frequency set hop from the current set to another set is needed based on the first group of one or more noise metrics regardless of the NM2 in the current set.

11. A capacitance sensing system, comprising:
a memory device; and
a controller coupled to the memory device, wherein the controller is configured to receive a signal from a sense network comprising a plurality of electrodes to detect a conductive object proximate to the plurality of electrodes, wherein the controller comprises:
a noise listening circuit configured to:
determine a first group of one or more noise metrics of noise in the signal; and
determine a second group of one or more noise metrics of the noise in the signal; and
a frequency selection state machine configured to:
perform a frequency hop within a first frequency set based on the first group of the one or more noise metrics, wherein the frequency hop switches from a first operating frequency in the first frequency set to a second operating frequency in the first frequency set; and
perform a frequency set hop from the first frequency set to a second frequency set based on the second group of the one or more noise metrics, wherein the frequency set hop is switches from the first operating frequency in the first frequency set to an operating frequency in the second frequency set.

12. The capacitance sensing system of claim 11, wherein a first separation in frequencies between the first frequency set and the second frequency set is greater than a second separation in frequencies within the first frequency set.

13. The capacitance sensing system of claim 11, wherein the first frequency set comprises three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the first frequency set, and wherein the second frequency set comprises two or more non-overlapping frequency bands, each centered at one of two operating frequencies of the second frequency set.

14. The capacitance sensing system of claim 11, wherein the noise listening circuit is configured to:
obtain a plurality of sub-conversions representing capacitance values measured on the plurality of electrodes;
calculate a third noise metric (NM3) based on the plurality of sub-conversions, wherein the NM3 represents an energy of the noise in the signal;
calculate a first noise metric (NM1) based on the plurality of sub-conversions, wherein the NM1 represents an average sum of absolute value maximums among the sub-conversions in a number of conversions; and
calculate a second noise metric (NM2) based on the plurality of sub-conversions,
wherein the second group of one or more noise metrics comprises the NM1 and the NM3, and
wherein the first group of one or more noise metrics comprises the NM2 and the NM1.

15. The capacitance sensing system of claim 14, wherein the noise listening circuit is configured to calculate the NM1, NM2, and NM3 based on the following equations:

$$NM2 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \cdot \left| \sum_{k=1}^{N_{sub}} SubConvData_{i,k} \right|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100,$$

where N is the number of conversions in a listening scan, $SubConvData_{i,k}$ is the plurality of sub-conversions in each of the number of conversions;

$$NM3 = \frac{\sum_{i=1}^{N} \frac{1}{N_{sub}} \sum_{k=1}^{N_{sub}} |SubConvData_{i,k}|}{\sum_{i=1}^{N} \max_i (\{|SubConvData|\})} \cdot 100; \text{ and}$$

$$NM1 = \frac{1}{N} \sum_{i=1}^{N} \max_i (\{|SubConvData|\}).$$

16. The capacitance sensing system of claim 11, wherein the noise listening circuit is configured to switch from the first operating frequency to an operating frequency in the second frequency set that is farthest away in frequency from the first operating frequency, when performing the frequency set hop.

17. A host device, comprising:
a display;
a capacitance sensing array disposed in connection with the display;
a touch screen controller coupled to the capacitance sensing array, wherein the touch screen controller comprises:
a capacitance sensing circuit coupled to the capacitance sensing array; and
a noise listening circuit coupled to the capacitance sensing array, wherein the noise listening circuit is configured to:
determine a first group of one or more noise metrics of noise in a signal;
determine a second group of one or more noise metrics of the noise in a signal;
perform a frequency hop within a first frequency set based on the first group of the one or more noise metrics, wherein the frequency hop switches from a first operating frequency in a first frequency set to a second operating frequency in the first frequency set; and
performing a frequency set hop from the first frequency set to a second frequency set based on the second group of the one or more noise metrics, wherein the frequency set hop switches from the first operating frequency in the first frequency set to an operating frequency in the second frequency set.

18. The host device of claim 17, wherein the first frequency set comprises three or more non-overlapping frequency bands, each centered at one of three operating frequencies of the first frequency set, and wherein the second frequency set comprises two or more non-overlapping frequency bands, each centered at one of two operating frequencies of the second frequency set.

19. The host device of claim 17, wherein the noise listening circuit is configured to switch from the first operating frequency in the first frequency set to an operating frequencies in the second frequency set that is farthest away in frequency from the first operating frequency when performing the frequency set hop.

* * * * *